Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas

Quarterly Technical Progress Report
January 1 – March 31, 2004

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Cooperative Agreement Number: DE-FC26-03NT41987

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Disclaimer

Abstract

This document summarizes progress on Cooperative Agreement DE-FC26-03NT41987, "Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas," during the time-period January 1, 2004 through March 31, 2004. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is being funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

Various sorbent materials will be injected upstream of low SCA ESP systems at Georgia Power's Plant Yates Unit 1 and Unit 2. Both Unit 1 and Unit 2 fire a low sulfur bituminous coal. Unit 1 is equipped with a JBR wet FGD system downstream of the ESP for SO_2 control. Unit 2 is not equipped with downstream SO_2 controls; however, a dual flue gas conditioning system is used to enhance ESP performance.

Short-term parametric tests were conducted on Units 1 and 2 to evaluate the performance of activated carbon sorbents. In addition, the effects of the dual flue gas conditioning system on mercury removal performance were evaluated as part of the short-term parametric test on Unit 2. Based on the results of the parametric tests, a single sorbent will be selected for longer term full-scale tests on Unit 1 to observe long term performance of the sorbent, and its effects on ESP and JBR FGD system operations and combustion byproduct properties. The results of this study will provide data required for assessing the performance, long-term operational impacts, and estimating the costs of full-scale sorbent injection processes for flue gas mercury removal.

This is the second full reporting period for the subject Cooperative Agreement. During this period, efforts included test plan development, design and installation of sorbent injection systems, planning, and short-term parametric testing of two sorbents on Units 1 and 2. This technical progress report provides an update on these activities.

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List of Acronyms

acfm	Actual cubic feet per minute
ACI	Activated Carbon Injection
APCD	Air pollution control device
APH	Air preheater
ASTM	American Society for Testing and Materials
CEM	Continuous emissions monitor
CO_2	Carbon dioxide
CT-121	Chyodia Thoroughbred - 121
CVAA	Cold vapor atomic absorption
$\triangle P$	“Delta P”, Pressure drop or pressure difference
DOE	Department of Energy
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Electrostatic precipitator
FGD	Flue gas desulfurization
FGD™	Norit America’s Darco FGD™ activated carbon
HCl	Hydrochloric acid
Hg	Mercury
IGS	Inertial gas separation
JBR	Jet bubbling reactor
LOI	Loss on ignition
MW	Megawatt
NETL	National Energy Technology Laboratory
NH_3	Ammonia
NIST	National Institute of Standards and Technology
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
OH	Ontario Hydro
PSD	Particle size distribution
QA/QC	Quality assurance/quality control
SCA	Specific collection area
SCEM	Semi Continuous Emission Monitor
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
U.S.	United States

1.0 Executive Summary

This document summarizes progress on Cooperative Agreement DE-FC26-03NT41987, "Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas," during the time-period January 1, 2004 through March 31, 2004. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is being funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

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The primary activities during this second quarter of the test program were preparation of a comprehensive test plan and quality assurance/quality control plan, design and installation of the injection systems for Units 1 and 2, completion of the sorbent selection process, and short term parametric testing for Units 1 and 2. Design and installation of the sorbent injection system was completed by ADA-ES in mid-February. Unit 1 parametric tests using Norit America's Darco FGD™ activated carbon were completed during the first week of March. Unit 1 and Unit 2 tests included both baseline characterization and sorbent injection tests at injection rates ranging from 2 to 13 lb/MMacf of Darco FGD™ activated carbon. Unit 2 parametric tests were conducted during the weeks of March 15th and March 22nd with the dual flue gas conditioning systems both on and off. The final set of short-term parametric tests for Unit 1 using a second activated carbon sorbent (Super HOK) supplied by RWE Rhinebraum were scheduled to be conducted during the week of March 29th; however, the shipment of the activated carbon was delayed by U.S. Customs. This testing has been rescheduled for early April 2004 and results will be presented in the next quarterly report. As a project add-on, a Chinese iodated carbon was made available to the project and was tested over a two-day period on Unit 1 the week of March 29th since the Super HOK carbon did not arrive on-site as scheduled. Results for the Chinese carbon will also be included in the next quarterly report. Key results from this quarter are summarized below.

Unit 1 and Unit 2 ESP Mercury Removal

During baseline testing on Unit 1 (SCA = 173 ft^2/1000 acfm), the average vapor-phase ESP inlet mercury concentration was 4.02 $\mu g/Nm^3$ and the average ESP outlet concentration was 2.64 $\mu g/Nm^3$ (at 3% O_2). On average, a 34% native removal across the ESP was measured during the baseline period. For Unit 2 (SCA = 144 ft^2/1000 acfm) , during the baseline week of testing, the average ESP inlet mercury concentration was 6.04 $\mu g/Nm^3$and the outlet was 3.89 $\mu g/Nm^3$, indicating 36% native removal.

During the weeks of Darco FGD™ carbon injection, native removals (i.e. no sorbent injection) of total vapor phase mercury were similar for both ESPs with values generally in the range of 20 to 50 percent. Injection of Darco FGD™ carbon increased removal to 45 to 60% across the ESP at injection rates of 2.3 to 4 lb/MMacf. Removal of vapor-phase mercury for the Unit 1 ESP was higher than what was observed for the Unit 2 ESP at the lower Darco FGD™ carbon injection rates of 2 lb/MMacf and 4 lb/MMacf; however, removal curves for both the Unit 1 and Unit 2 ESPs were relatively flat at about 60 to 70 percent removal for injection rates greater than 6 lb/MMacf.

Baseline total vapor-phase mercury emissions at the Unit 1 ESP outlet were between 2.1 lb/trillion Btu and 2.9 lb/trillion Btu. Injection of Darco FGD™ activated carbon upstream of the Unit 1 ESP reduced vapor-phase mercury emission below 2 lb/trillion Btu at injection rates greater than 4 lb/MMacf.

Tests on Unit 2 were conducted with the dual flue gas conditioning system off and on at various NH_3/SO_3 injection rates; however, flue gas conditioning was found to have no effect on total vapor-phase mercury removal across the ESP.

Since native removals were quite high, mercury removal was also evaluated as the percent reduction in mercury achieved at the ESP outlet as compared to the daily baseline ESP outlet concentration to quantify performance improvements attributed to carbon injection. These data indicate similar percent reductions were achieved for both the Unit 1 and Unit 2 ESP systems during injection of Darco FGD™ carbon. Maximum reductions of about 40 percent were observed at injection rates in the range of 4 to 6 lb/MMacf with little additional reduction observed at the higher injection rates.

Impacts of Sorbent Injection on ESP Performance

Injection of Darco FGD™ activated carbon upstream of the Unit 1 ESP resulted in increased arc rates within all fields of the ESP with arc rates becoming more severe as the carbon injection rate was increased. Similar behavior was seen on Unit 2. Typical arc rates for the Yates Unit 1 and Unit 2 ESP systems are 0 to 1 arc/min. Sustained arc rates greater than 10 arc/min may cause damage to the ESP. At times during carbon injection, arc rates greater than 10 arc/min were experienced on both Units 1 and 2. The plant process data are being reviewed to examine the correlation between ESP behavior, carbon injection rate, and flue gas conditioning.

Unit 1 JBR Mercury Removal

No increase in vapor-phase mercury removal was observed across the JBR scrubber system during Darco FGD™ carbon injection tests and no increase in the percent mercury oxidation at the ESP outlet (JBR inlet) sample location was observed. When compared to the daily baseline measurements, mercury measurements at the outlet of the Unit 1 JBR indicated reductions of 10 to 30 percent in total vapor-phase mercury concentrations for injection rates in the range of 2.3 to 12.7 lb/MMacf. These reductions in JBR outlet mercury concentrations are attributed to corresponding reductions in the mercury concentrations at the ESP outlet (JBR inlet) rather than an increase in the mercury removal performance of the JBR scrubber system.

2.0 Experimental

Experimental-related activities conducted during this quarter included the finalization of the test plan, sorbent selection, installation of the sorbent injection equipment for the parametric tests, baseline (no injection) testing of Units 1 and 2, and parametric tests of Darco FGD™ activated carbon injection for Units 1 and 2.

2.1 Plant Configuration

Figures 2-1 and 2-2 show the basic plant configuration, sorbent injection points, and flue gas sample locations for Units 1 and 2, respectively. Characteristics of each unit are summarized in Table 2-1.

Table 2-1. Plant Yates Unit 1 and 2 Configurations

	Yates Unit 1	Yates Unit 2
Boiler		
Type	CE Tangential Fired	
Nameplate (MW)	100	
Coal		
Type	Eastern Bituminous	
Sulfur (wt %, dry)	1.0	
Mercury (mg/kg, dry)	0.16	
Chloride (mg/kg, dry)	300-1400	
ESP		
Type	Cold-Side	
ESP Manufacturer	Buell (1968 and 1971 vintage, refurbished in 1997)	
Specific Collection Area (ft^2/1000afcm)	173	144
Plate Spacing (in.)	11	
Plate Height (ft)	30	
Electrical Fields	3	2
Mechanical Fields	4	3
ESP Inlet Temp. (°F)	310	300
ESP Design Flow Rate (ACFM)	490,000	420,000
NO_x Controls	Low NOx Burners	None
SO_2 Controls	Chiyoda CT-121 wet scrubber (JBR)	None
Flue Gas Conditioning	None	Dual NH_3/SO_3

2.2 Experimental Methods

The sorbent injection equipment was described in the previous technical report. The mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers, which are described below in more detail. For each sorbent injection test, particulate loading was measured via Method 17. During baseline testing, Ontario Hydro, Method 26a measurements for halogens, and particulate loading via Method 5 were conducted. These methods are not explained further, as they are considered standard methods.

Solid and liquid samples, such as makeup water, fly ash, and coal, were collected and analyzed for mercury content. Fly ash and coal mercury were digested with ASTM 3684 and analyzed for mercury by CVAA. The coal was digested by ASTM 4208 and analyzed for chloride by Method 300.

EPRI SCEM Mercury Analyzer

Additional details regarding the SCEM mercury analyzer are provided in this section since it is not standard EPA method. Flue gas vapor-phase mercury analyses were made using EPRI semi-continuous analyzers depicted in Figure 2-3. At each sample location, a sample of the flue gas is extracted from the duct and then pass through an inertial gas separation (IGS) filter to remove particulate matter. This IGS filter consists of a heated stainless steel tube lined with sintered material. A secondary sample stream is pulled across the sintered metal filter and then is directed through the mercury analyzer at a rate of approximately 1-2 L/min thus providing near real-time feedback during the various test conditions. The analyzer consists of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). Since the Au-CVAAS measures mercury by using the distinct lines of the UV absorption characteristics of elemental mercury, the non-elemental fraction is converted to elemental mercury prior to analysis using a chilled reduction solution of acidified stannous chloride. Several impingers containing alkaline solutions are placed downstream of the reducing impingers to remove acidic components from the flue gas; elemental mercury is quantitatively transferred through these impingers.

Gas exiting the impingers flows through a gold amalgamation column where the mercury in the gas is adsorbed (<60° C). After adsorbing mercury onto the gold for a fixed period of time (typically 1 minute), the mercury concentrated on the gold is thermally desorbed (>500° C) in nitrogen or air, and sent as a concentrated mercury stream to a CVAAS for analysis. Therefore, the total flue gas mercury concentration is measured semi-continuously with a 1-minute sample time followed by a 2-minute analytical period. The analyzer sampling time is set to ensure collection of nominally 3 ng of mercury per sampling cycle. The noise level of the analyzer is approximately 0.3 ng.

To measure elemental mercury only, an impinger containing either 1M potassium chloride (KCl) or 1M Tris Hydroxymethyl (aminomethane) and EDTA is placed upstream of the alkaline solution impingers to capture oxidized mercury. Oxidized forms of mercury were subsequently captured and maintained in the KCl or Tris impingers while elemental mercury passes through to the gold system. Comparison of "total" and "elemental" mercury measurements yields the extent of mercury oxidation in the flue gas.

2.3 Progress by Task

Progress on the various project tasks are described in the following sections. A summary of progress is provided in Table 2-2.

Task 1 – Project Planning

Sorbent Selection

Final selection of the activated carbon sorbents to be used during the project was completed during this quarter. Table 2-3 shows details about the sorbents selected for testing.

The Darco FGD™ carbon will serve as the benchmark sorbent since it has been used in numerous other sorbent injection test programs and its performance characteristics are well defined. The Super HOK sorbent is a German lignite-derived activated carbon selected based on its cost, performance in previous tests and availability in quantities necessary for this test program. The third sorbent, a Chinese iodated activated carbon, was not originally included in the test plan, but was made available at no cost to the project and tested over a two-day period on Unit 1 when the Super HOK carbon did not arrive on-site as planned. The project team made the decision to test this chemically treated activated carbon because total vapor-phase mercury removal for the Darco FGD™ activated carbon showed a plateau at about 70 percent removal during tests conducted on both the Unit 1 and Unit 2 ESP earlier in March. The Chinese carbon offered the potential for removals greater than 70 percent, although the cost is about 75% higher than that of the benchmark Darco FGD™ carbon.

Table 2-2. Schedule for FY 2004 Milestones for this Test Program

Milestone	Description	Planned Completion	Actual Completion
1	Hazardous substance plan	Q1	Q1
2	Project kickoff meeting	Q1	Q1
3	Site Survey – Units 1 and 2	Q1	Q1
5	Test plan – Units 1 and 2	Q1	Q2
6	Complete sorbent injection system installation for parametric tests – Units 1 and 2	Q2	Q2
7	Complete baseline and parametric tests for sorbent 1 (Darco FGD™ carbon) on Units 1 and 2	Q2	Q2
8	Complete baseline and parametric tests for sorbent 2 (Super HOK carbon) on Unit 1	Q3	
9	Transfer and install ACI silo and feeder system on Unit 1 for long-term tests	Q4	
10	Initiate long-term test on Unit 1	Q4	
11	Complete long-term test on Unit 1	Q4	
12	Complete data workup for Units 1 and 2	Q1-FY2005	
13	Initiate economic analysis	Q1-FY2005	

Table 2-3. Sorbents Selected for Test Program

Carbon Name	Manufacturer	Description	Cost ($/lb)
Darco FGD™	Norit Americas	Lignite-derived activated carbon; baseline carbon (19 µm mean particle size)	0.50
Super HOK	RWE Rhinebraun	German lignite-derived activated carbon (23 µm mean particle size)	0.35 [a]
Chinese Carbon	Ningxia Huahui Activated Carbon Co. LTD (HHAC)	Chinese iodated bituminous-derived activated carbon (24 µm mean particle size)	0.88

a = F.O.B. Pennsylvania

Test Plan, QA/QC Plan, and Health and Safety Plan

A combined test plan and quality assurance/quality control plan for the project was developed and submitted to NETL. In addition, a site-specific health and safety plan was prepared.

Task 2 – Unit 1 Testing

Injection lances were designed and installed by ADA-ES at the Unit 1 ESP inlet location using the port configuration shown in Figure 2-4. Six injection lances fabricated from 1-inch pipe were placed at approximately equal spacing across the width of the duct. Each lance projects horizontally into the 8 ft-6 inch deep duct and ends at approximately 4 ft into the duct. The duct is approximately 60 ft wide at this location. Each lance is open ended with no orifices along the lance. The pneumatically conveyed sorbent exits the lance end and mixes with the flue gas flowing vertically in the duct before entering the ESP. The lance configuration for Unit 2 was similar to the Unit 1 design.

For the short-term parametric tests on Unit 1, a Port-a-Pac sorbent injection system, designed to feed dry material from super sacs, was installed to service both the Unit 1 and Unit 2 ESP inlet injection points. This portable dry injection system pneumatically conveys a predetermined and adjustable amount of powdered activated carbon (PAC) from bulk bags into the flue gas stream via six sorbent injection lances. The Port-a-Pac unit consists of two eight-foot tall sections. PAC is metered using a volumetric feeder into a pneumatic eductor, where the air supplied from the regenerative blower provides the motive force needed to transport the carbon to the final injection locations. The Port-a-Pac can deliver from 20 – 365 lb/hr of activated carbon.

Short-term baseline and parametric tests using the Darco FGD™ activated carbon were conducted the weeks of February 23rd and March 1st, respectively. The testing schedules are summarized in Tables 2-4 and 2-5.

Task 3 – Unit 2 Testing

Injection lances were designed and installed by ADA-ES at the Unit 2 ESP inlet location using the identical port configuration shown previously in Figure 2-4. The same Port-a-Pac system and injection lance design described above was used for the Unit 2 tests. The dual flue gas conditioning system for Unit 2 is installed in the same run of duct used for sorbent injection.

Table 2-4. Unit 1 Baseline Test Schedule

	2/25/04						2/26/04						2/27/04					
Time	8am	10am	12pm	2pm	4pm	6pm	8am	10am	12pm	2pm	4pm	6pm	8am	10am	12pm	2pm	4pm	6pm
								Duct A		Duct B		Duct B						
ESP Inlet:																		
Ontario Hydro								←→		←→		←→						
SCEM				←	—	—	—	—	—	—	—	—	→	Duct A				
M26A		←→	←→	←→	←→	←→	Duct B											
ESP Outlet:																		
Ontario Hydro								←→		←→		←→						
SCEM		←	—	—	—	—	—	—	—	—	—	—	→					
M26A and Loading		←→	←→	←→	←→	←→												
Stack Outlet:																		
SCEM		←	—	—	—	—	—	—	—	—	—	—	→					
Coal:																		
Grab Composite	●		●					●	●				●		●			
ESP Fly Ash:																		
Grab Composite		●	●					●							●			
DOE Characterization	●		●					●						●				
JBR FGD Gypsum:																		
Grab Composite										●								
Makeup Water:																		
Grab Composite										●								
Limestone:																		
Grab Composite										●								
Bottom Ash:																		
Grab Composite									●									

Table 2-5. Unit 1 Parametric Sorbent Injection Test Schedule for Darco FGD™ Activated Carbon

	3/1/04			**3/2/04**			**3/3/04**						**3/4/04**					
Test Condition	BL	SI	BL	BL	SI	BL	BL	SI	SI	SI	SI	BL	BL	SI	SI	SI	SI	BL
Begin/End Time (EST)	8:35 – 9:06	9:10 - 18:00	18:30 – 19:15	7:45 – 10:30	10:30 - 14:47	15:36 – 16:13	1:00 – 9:05	9:08 – 12:33	12:33 – 13:43	13:43 – 15:00	15:00 – 17:45	17:52 – 19:10	9:35 – 10:03	10:03 – 12:29	12:29 – 15:25	15:25 – 17:50	17:50 – 18:45	19:05 – 19:55
Injection Rate (lb/MMacf)	0	6.3	0	0	12.7	0	0	2.1	4.2	2.1	3.1	0	0	5.2	7.3	9.4	12.7	0
Injection Rate (lb/h)	0	180	0	0	365	0	0	60	120	60	90	0	0	150	210	270	365	0
ESP Inlet SCEM	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
ESP Outlet SCEM	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
M17		X			X			X	X						X	X		
Stack SCEM	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coal	-	10:00, 13:05	-	9:30	13:05	-	-	9:30	13:10	-	-	-	9:10	-	13:00	-	-	-
ESP Fly Ash	-	11:00	-	-	13:30	-	-	-	13:35	-	-	-	-	-	13:00	-	-	-

C = Indicates continuous SCEM operation during test period. Other entries indicate the times (EST) that samples were collected.

BL = Baseline (no injection)

SI = Sorbent Injection

The sorbent injection point was located downstream of the NH_3 injection point and upstream of the SO_3 injection point.

Short-term baseline tests were conducted the week of March 15th and parametric tests using the Darco FGD™ activated carbon were conducted the week of March 22nd. The test schedule for these periods is summarized in Tables 2-6 and 2-7, respectively.

Task 4 – Data and Economic Analysis

Analytical and process data from the Unit 1 and Unit 2 parametric tests were reduced and analyzed. Process data from the plant for Unit 2 tests have not been received. These data will be reviewed in relation to test results during the next quarter. No activity was planned related to the economic analysis.

Task 5 – Waste Characterization

Samples of ESP fly ash, JBR FGD scrubber solids and liquid, limestone and makeup water were collected from Unit 1 during the baseline and Darco FGD™ activated carbon test series the weeks of February 23rd and March 1st as outlined above in Tables 2-4 and 2-5. Bulk samples for DOE byproduct characterization were collected during the Unit 1 baseline test periods and held for future analysis by a DOE–selected laboratory. Grab samples to be used for material balance evaluations were also collected and submitted to a URS laboratory for analysis. Grab samples of ESP fly ash were collected from each field of the ESP and combined to obtain an overall composite. Ash samples were analyzed for mercury and LOI. Grab samples of the JBR FGD gypsum byproduct were collected and gravity filtered to obtain solid and liquid fractions which were analyzed for mercury. Limestone and JBR FGD system makeup water samples were also collected and analyzed for mercury.

Likewise, grab samples of coal and ESP fly ash were collected from each field of the ESP during the Unit 2 baseline and Darco FGD™ activated carbon injection tests. Samples were analyzed for mercury and LOI. Bulk samples of ESP ash for DOE waste characterization tests were collected as shown in Table 2-5 and held for future analysis. The plant was down during the day of March 17; therefore, no solid samples were taken that day.

Table 2-6. Unit 2 Baseline Test Schedule

	3/17/04						3/18/04						3/19/04					
Time	8am	10am	12pm	2pm	4pm	6pm	8am	10am	12pm	2pm	4pm	6pm	8am	10am	12pm	2pm	4pm	6pm
ESP Inlet:																		
Ontario Hydro								↔	↔		↔							
SCEM						←	—	—	—	—	—	—	—	—	—	—	—	→
M26A						↔	↔							↔				
ESP Outlet:																		
Ontario Hydro SCEM						←	—	↔ —	↔ —	—	↔ —	—	—	—	—	—	—	→
Coal:																		
Grab Composite								●	●					●	●			
ESP Fly Ash:																		
Grab Composite									●						●			
DOE Characterization Sample									●						●			

Table 2-7. Unit 2 Parametric Sorbent Injection Test Schedule for Darco FGD™ Activated Carbon

Date	**3/22/04**				**3/24/04**				
Test Condition	BL	SI	SI	BL	BL	SI	SI	SI	BL
Begin/End Time (EST)	10:32 - 11:45	11:45 - 15:25	15:25 - 16:30	16:30 – 20:39	8:20 - 13:25	13:25 - 16:11	16:11 - 17:14	17:14 - 18:11	18:11- 18:31
Injection Rate (lb/MMacf)	0	2.1	4.2	0	0	6.3	8.3	12.7	0
Flue Gas Conditioning [a]	Full	Full	Full	Full	Full	Full	Full	Full	Full
ESP Inlet SCEM	C	C	C	C	C	C	C	C	C
ESP Outlet SCEM	C	C	C	C	C	C	C	C	C
M17 Loading			X			X	X	X	
Coal	9:45	13:30	-	-	13:20	-	-	-	-
ESP Fly Ash	-	13:30	-	-	13:20	-	-	-	-

Date	**3/25/04**						**3/26/04**					
Test Condition	BL	SI	SI	SI	BL	BL	BL	SI	SI	SI	SI	BL
Begin/End Time (EST)	8:22 - 9:57	9:57 - 13:11	13:11 - 16:00	16:00 - 17:30	17:30 - 18:14	18:14 - 18:54	8:23 - 9:57	9:57 - 12:46	12:46 - 14:30	14:30 - 15:40	15:40 - 16:15	16:15 - 20:25
Injection Rate (lb/hr)	0	2.1	4.2	4.2	4.2	0	0	4.2	4.2	4.2	4.2	0
Flue Gas Conditioning [a]	None	None	None	Half	None	None	Full	Full	Half	Full	Low NH_3	Full
ESP Inlet SCEM	C	C	C	C	C	C	C	C	C	C	C	C
ESP Outlet SCEM	C	C	C	C	C	C	C	C	C	C	C	C
M17 Loading		X	X					X	X			
Coal	-	-	13:20	-	-	-	-	-	13:21	-	-	-
ESP Fly Ash	-	-	13:30	-	-	-	-	-	13:30	-	-	-

[a] Full = NH_3 ~ 6 ppm, SO_3 ~ 10 ppm;
Half = NH_3 ~ 3 ppm, SO_3 ~ 5 ppm;
Low NH_3 = NH_3 ~ 2 ppm, SO_3 ~ 10 ppm; and
None = Conditioning System Off
C = Indicates continuous SCEM operation during test period. Other entries indicate the times (EST) that samples were collected

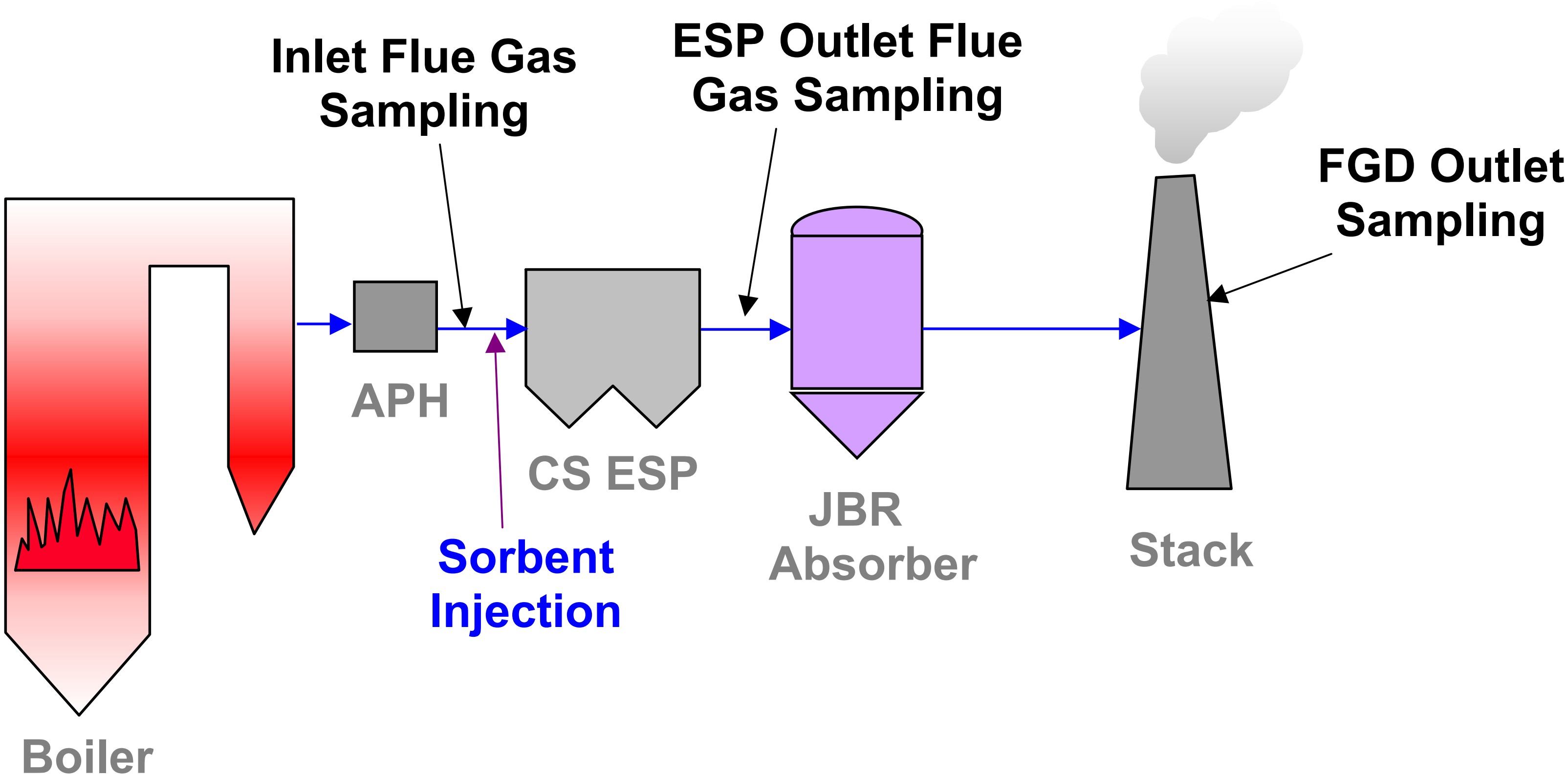

Figure 2-1. Unit 1 Configuration and Flue Gas Sample Locations

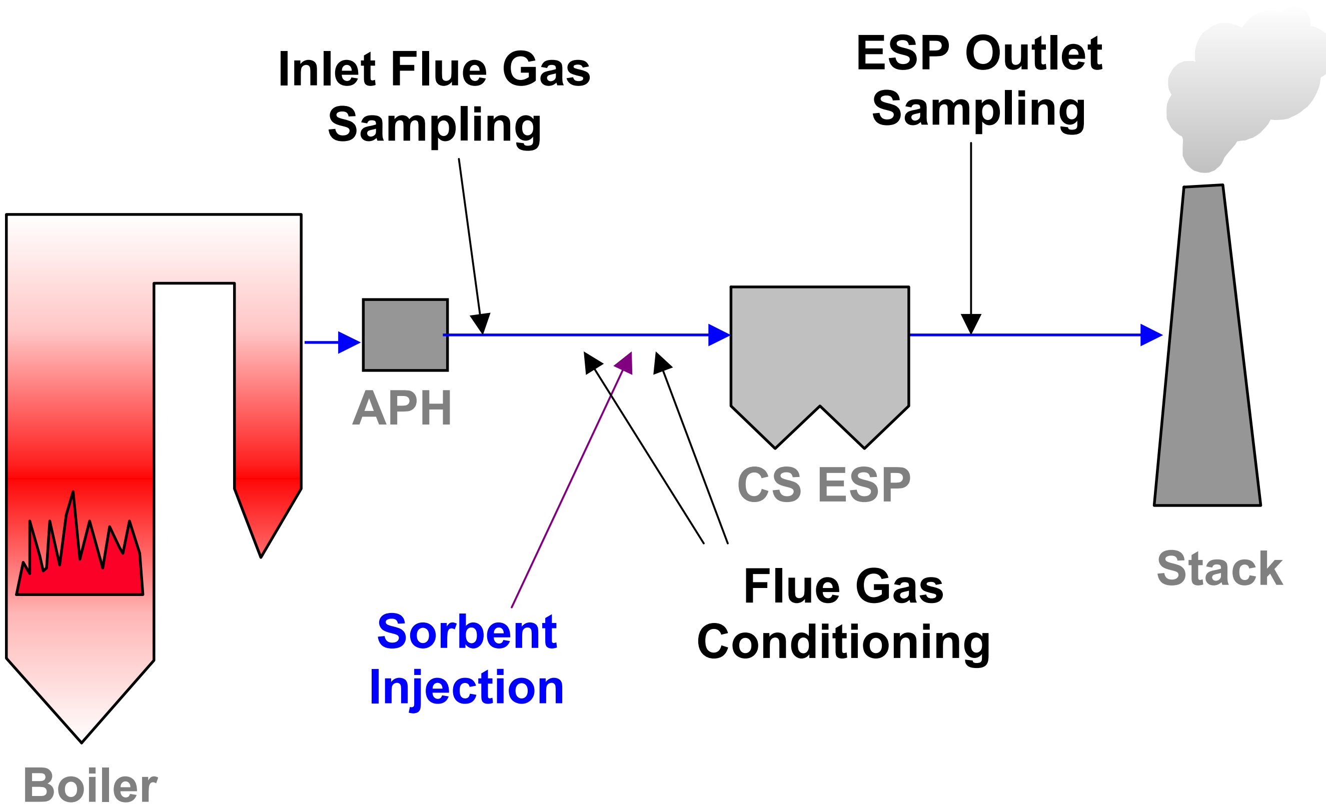

Figure 2-2. Unit 2 Configuration and Flue Gas Sample Locations

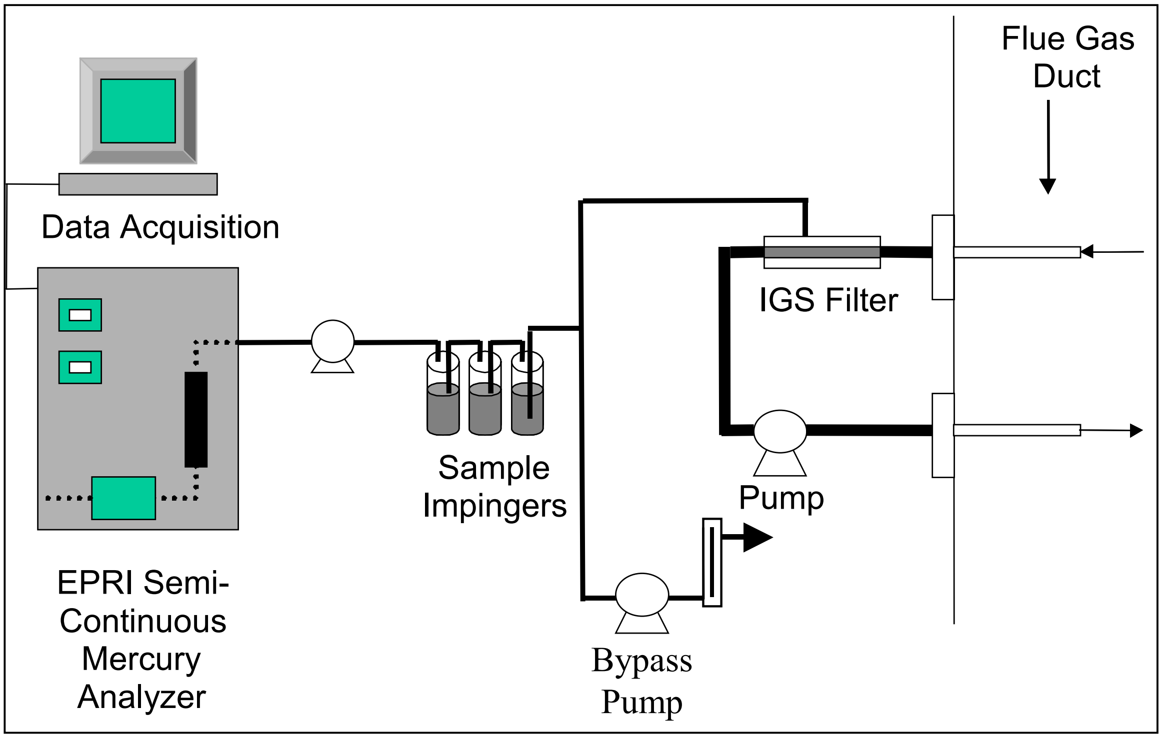

Figure 2-3. Semi-Continuous Mercury Analyzer

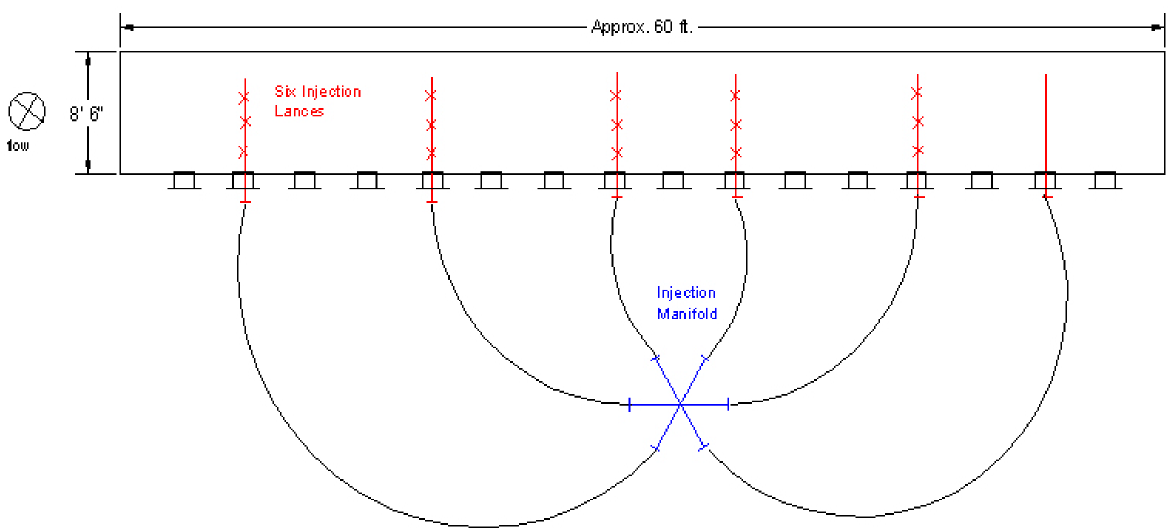

Figure 2-4. Unit 1 and 2 ESP Inlet Sorbent Injection Port Configuration

3.0 Results and Discussion

Currently available results for the baseline and parametric Darco FGD™ activated carbon injection tests conducted on Units 1 and 2 during March are discussed in this section. Results for the Unit 1 parametric tests using the Chinese and HOK activated carbon will be included in the next quarterly report for this project.

3.1 Unit 1 Parametric Testing

Flue gas mercury measurements for the Unit 1 parametric tests are presented below, along with a summary of test conditions and any deviations from the test plan, a discussion of the effects of sorbent injection on plant operations, results for additional solid and liquid process streams, and results for additional flue gas characterization samples.

3.1.1 Test Conditions and Modification to Test Plan

Field test conditions for the Unit 1 Darco FGD™ activated carbon parametric tests are summarized below in Table 3-1. All sampling activities were completed as planned. Comprehensive baseline characterization of the Unit 1 system was conducted on Day 1 through Day 3; sorbent injection tests were conducted on Days 4 through 7. Sorbent injection rates for the tests were modified slightly from those target rates specified in the test plan because of the carbon feed rate limitations of the Port-a-Pac system. As a result, the high-end injection rate of 20 lb/MMacf could not be tested. However, as discussed further in Section 3.1.2 below, ESP operations were significantly impacted by the injection of Darco FGD™ carbon at the lower rates, so injection at the highest rate of 20 lb/MMacf would not have been technically feasible without risking possible damage to the ESP system.

Because of the relatively short time necessary for flue gas mercury concentrations to reach steady state once carbon injection began and the need to further observe the effects of carbon injection on ESP performance, testing of multiple carbon injection rates was possible on Days 6 and 7 as indicated in Table 3-1.

Table 3-1. Field Test Conditions for the Unit 1 Baseline and Darco FGD™ Carbon Parametric Tests

Date	Baseline, Full Load			Darco FGD™ Carbon Injection, Full Load								
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**			**Day 7**			
	2/25/04	**2/26/04**	**2/27/04**	**3/1/04**	**3/2/04**	**3/3/04**			**3/4/04**			
Injection Time Period (EST)	NA	NA	NA	9:10 – 18:00	10:30 – 14:47	9:08 – 12:33	12:33-13:43	15:00 – 17:45	10:03 – 12:29	12:29 – 15:00	15:25 – 17:50	17:50 – 18:45
Target Injection Rate (lb/MMacf)	0	0	0	5	10	15			20			
Actual Injection Rate (lb/MMacf)	0	0	0	6.3	12.7	2.1	4.2	3.1	5.2	7.3	9.4	12.7
Actual Injection Rate (lb/hr)	0	0	0	180	365	60	120	90	150	210	270	365

3.1.2 Unit 1 Process Operations

Boiler Operation

Unit 1 load was increased to its full-load set point of approximately 106 MW before each baseline and sorbent injection test period and held constant throughout each test.

ESP Performance

Flue gas temperatures at the air heater outlet (ESP inlet) and ESP outlet, as measured by plant instrumentation, are shown in Figure 3-1. Flue gas temperatures at the air heater outlet (ESP inlet) and ESP outlet locations increased by approximately 30 to 40 degrees Fahrenheit when Unit 1 load was increased from approximately 50 percent to full load. Flue gas temperatures were about 20 degrees Fahrenheit higher during the full-load baseline test periods (2/25/04 to 2/27/04) compared to the full-load sorbent injection test periods (3/1/04 to 3/4/04). A 20 to 30 degree Fahrenheit decrease in temperature was observed between the ESP inlet and ESP outlet measurement locations, presumably due to air inleakage across the ESP and gas cooling in the approximately 50-foot run of duct between the outlet of the ESP and the outlet temperature measurement point. As discussed further in Section 3.1.3, these changes in flue gas temperature may have contributed to differences in the total vapor-phase mercury levels observed in the flue gas during reduced-load and full-load conditions, particularly at the ESP inlet location.

The impact of sorbent injection on the ESP performance was quantified by taking Method 17 particulate samples during each injection rate and by monitoring the arc rate in each field. Results from the Method 17 filters are not available yet. The results will be reported in the next quarterly report. Arc rate data were monitored on the plant's ESP control system. Observations from the testing are now reported. A more detailed assessment in which the data from the ESP control system is compared with process data will be performed next quarter.

The typical arc rate for the Unit 1 ESP is 0-1 arc/minute. According to the Plant Yates engineers, sustained arc rates greater than 10 arc/min are considered unacceptable and may damage the ESP. During the carbon injection testing, arc rates reached 10 arc/min, and in some cases exceeded this value.

In general, the ESP on Unit 1 experienced higher than normal arc rates during injection of Darco FGD™ carbon. On any given test day, the arc rate appeared to be directly correlated to the injection rate of the carbon. Figure 3-2 plots the arc rates for each field on a single test day; the inlet field is shown at the top of the figure. The light gray step function shows the carbon injection rate. As the carbon injection rate increases, the arc rate correspondingly increases on each field.

The day-to-day electrical response of the ESP seemed to vary. For example, on the first day of testing (3/1), 180 lb/hour of Darco FGD™ carbon was injected into the ESP, and no significant increase in arc rate was noted. On a later day (3/3), injection of Darco FGD™ carbon at rates as low as 60 lb/hour resulted in a noticeable increase in arc rate. Therefore, other process parameters, such as coal sulfur content, may play a role in how Darco FGD™ carbon injection affects the electrical response of the ESP. These parameters will be explored further once all of the coal and process data are retrieved.

JBR Scrubber Performance

No noticeable difference was observed in the operation of the JBR wet scrubber system during the full-load baseline and the carbon injection test periods. Plant continuous emissions monitor (CEM) data for stack SO_2, stack NO_x, duct opacity, and stack temperature are shown in Figure 3-3. Key JBR scrubber process parameters during the test periods are shown in Figure 3-4. SO_2, NO_x and duct opacity measurements remained relatively constant during each full-load test period; however, notable differences were observed between full-load and reduced-load operation. SO_2 concentrations and duct opacity were higher at the full-load conditions, while NO_x levels were lower at full-load. The most significant change for the JBR system was the increase in the flue gas temperature at the stack caused by increasing Unit 1 load prior to each test period. This temperature increase was particularly evident during the sorbent injection test periods on 3/1/04 through 3/4/04.

3.1.3 Mercury Speciation and Removal Data for Unit 1

Baseline Characterization Tests

Baseline characterization of the mercury concentrations in the flue gas at the ESP inlet, ESP outlet, and stack locations were conducted over a three-day period on 2/25/04 through 2/27/04. During this period, semi-continuous data were collected for total vapor-phase mercury and elemental mercury (oxidized mercury calculated by difference) using three SCEM analyzers. In addition, simultaneous Ontario Hydro mercury speciation measurements were conducted at the ESP inlet and ESP outlet during full-load conditions to compare to the SCEM analyzer results. The objectives of this series of tests were: 1) to measure the native mercury concentrations at the various flue gas sample locations; 2) to measure the variability in flue gas mercury concentrations over time; and 3) to compare the performance of the SCEM analyzers with results from the Ontario Hydro standard reference method.

Table 3-2 provides a comparison of the baseline mercury measurements for the SCEM and Ontario Hydro methods. The average total and elemental mercury concentrations measured by the SCEM during the course of each two-hour Ontario Hydro run are reported. The SCEM measured ESP inlet concentrations between 3.92 and 4.12 $\mu g/Nm^3$ at 3% O_2, with an average of 4.02 $\mu g/Nm^3$. The three Ontario Hydro runs measured 9.48, 2.97, and 3.17 $\mu g/Nm^3$ at the ESP inlet. At the ESP outlet, the SCEM measured 3.49, 2.26, and 2.18 $\mu g/Nm^3$, while the Ontario Hydro runs measured 7.41, 3.75, and 3.34 $\mu g/Nm^3$. At the ESP inlet, the Ontario Hydro data are lower than the SCEM data for runs 2 and 3. At the ESP outlet, Ontario Hydro values are higher than the SCEM outlet values. In addition, the outlet Ontario Hydro values are greater than the inlet Ontario Hydro values. Particulate mercury concentrations are not available at the ESP inlet since the ESP inlet sampling location was nestled between two sharp turns in the duct work, making isokinetic sampling infeasible. The ESP outlet particulate mercury concentrations, as determined by the Ontario Hydro method, were 0.0035, 0.0011, and 0.0195 $\mu g/Nm^3$.

The discrepancies between the SCEM and Ontario Hydro results are currently under investigation. Furthermore, the differences between the first Ontario Hydro run and the subsequent runs are being explored. A review of the QC spike recovery data for the SCEM method does not indicate any problem with these data.

The variability in SCEM total vapor-phase and elemental mercury concentrations at the ESP inlet, ESP outlet and Stack locations during baseline test periods are shown in Figures 3-5, 3-6 and 3-7, respectively. As shown in Figure 3-5, the variability in total vapor-phase mercury concentrations was greatest at the ESP inlet location. The effects of load changes on total vapor-phase mercury levels were also most evident at the ESP inlet, where total vapor-phase mercury concentrations increased from 1 to 3 $\mu g/Nm^3$ at reduced load to 4 to 7 $\mu g/Nm^3$ during full-load conditions.

Table 3-2. Unit 1 - Comparison of Average SCEM and Ontario Hydro Mercury Measurements During Baseline Characterization on 2/26/04

	Run No.	Sampling Period (EST)	Vapor Phase			
			Elemental	Oxidized	Percent Oxidized	Total
ESP Inlet, µg/Nm³						
SCEM	1	10:33-12:33	2.06	1.96	49	4.02
OH	1		1.32	8.15	86	9.48
SCEM	2	14:32-16:32	1.92	2.20	53	4.12
OH	2		0.31	2.66	89	2.97
SCEM	3	17:02-19:02	1.89	2.03	52	3.92
OH	3		0.43	2.74	86	3.17
SCEM	Avg	-	1.95	2.07	51	4.02
OH	Avg	-	0.69	4.51	88	5.20
ESP Outlet, µg/Nm³						
SCEM	1	10:33-12:33	2.16	1.33	38	3.49
OH	1		5.55	1.86	25	7.41
SCEM	2	14:30-16:30	1.48	0.78	35	2.26
OH	2		1.83	1.92	51	3.75
SCEM	3	17:02-19:02	1.383	0.80	37	2.18
OH	3		1.78	1.56	47	3.34
SCEM	Avg	-	1.67	0.97	37	2.64
OH	Avg	-	3.05	1.78	41	4.83
Removal, %						
SCEM	Avg	-	14	53	NA	34
OH	Avg	-	-342	61	NA	7

Note: All data normalized to 3% oxygen. Oxidized mercury for SCEM calculated as difference between measured total and elemental mercury. Total mercury for OH calculated as sum of measured elemental and oxidized mercury.

Sorbent Injection Tests

Table 3-3 provides a summary of the average total vapor-phase mercury and mercury speciation data obtained for the sorbent injection tests using the SCEM mercury analyzer. The oxidized mercury concentration is calculated by difference using the total and elemental mercury measurements. A set of baseline mercury measurements with no injection was obtained at the beginning and at the end of each sorbent injection test day to provide a benchmark for the sorbent injection tests. At the ESP inlet location, the percentage of the total mercury present as oxidized mercury remained essentially unchanged between daily baseline and sorbent injection tests periods, with values generally in the range of 46 to 55 percent. These values were consistent with SCEM data obtained during the baseline characterization period of 2/25/04 through 2/27/04.

Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-3, are provided in Table 3-4. Total vapor-phase mercury removal (i.e., ESP inlet compared to ESP outlet) is plotted as a function of sorbent injection rate in Figure 3-8 for the various test days. This calculation does not account for removal of particulate mercury across the ESP. Like the baseline characterization tests on 2/25/04 through 2/27/04, relatively high native removals of total vapor-phase mercury were observed without sorbent injection at the beginning and end of each sorbent injection test day. Native removal of total vapor-phase mercury across the ESP ranged from 26 to 53 percent, with the majority of values for non-injection periods concentrated between 35 and 50 percent, which probably results from the high carbon content of the ash generated by Unit 1 (approximately 10-13 percent LOI during the baseline test period). For the ESP system, a continuous increase in total mercury removal is observed with increasing sorbent injection rate. Total vapor-phase mercury removal across the ESP at the highest injection rate of 12.7 lb/MMacf ranged from 60 to 70 percent.

Figure 3-9 shows the total vapor-phase mercury emissions, expressed as lb/trillion Btu input, at the ESP outlet as a function of carbon injection rate. The corresponding daily baseline vapor-phase mercury concentrations are also provided for comparison. Without injection, the ESP outlet emissions ranged from 2.1 to 2.9 lb/trillion Btu. Darco FGD carbon injection rates of greater than 4 lb/MMacf were required to reduce ESP outlet emissions below 2 lb/trillion Btu. Beyond injection rates of 6 lb/MMacf, vapor-phase mercury emissions remained relatively constant.

Table 3-3. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Darco FGD™ Activated Carbon

Date	Injection Rate (lb/MMacf)	ESP Inlet, μg/Nm^3			ESP Outlet, μg/Nm^3			Stack, μg/Nm^3		
		Total	Hg^o	Percent Oxidized	Total	Hg^o	Percent Oxidized	Total	Hg^o	Percent Oxidized
3/1/04	0	7.3	2.5	66	3.8	2.3	40	1.8	1.8	1
	6.3	5.2	-	-	2.2	1.5	32	0.91	0.82	10
	0	5.2	-	-	3.8	-	-	1.2	-	-
3/2/04	0	6.9	3.6	47	3.3	2.4	25	2.5	2.3	8
	12.7	6.4	3.3	49	1.9	1.3	29	1.9	1.8	3
	0	5.9	2.8	52	3.2	-	-	2.7	-	-
3/3/04	0	7.8	3.6	54	4.3	1.9	57	2.6	2.0	23
	2.1	7.8	3.6	54	3.4	1.8	49	2.3	2.3	1
	4.2	6.9	3.3	52	2.9	-	-	2.2	-	-
	2.1	7.0	-	-		1.6	-	2.4	-	-
	3.1	7.2	3.3	55	3.1	1.5	52	1.9	2.2	0
	0	5.8	-	-	4.3	-	-	2.1	-	-
3/4/04	0	5.9	3.0	49	3.5	1.8	49	2.3	1.9	21
	5.2	6.2	3.0	51	2.4	1.3	48	1.8	1.7	2
	7.3	5.8	2.9	51	2.2	1.3	42	1.1	1.8	0
	9.4	5.5	3.1	43	2.0	1.2	40	1.6	1.7	0
	12.7	5.5	-	-	2.0	-	-	1.9	-	-
	0	5.8	3.1	46	4.0	-	-	3.1	-	-

Note: All concentrations normalized to 3% oxygen.

Table 3-4. Summary of Measured Vapor-Phase Mercury Removals for the Unit 1 ESP and JBR FGD During Injection of Darco FGD™ Activated Carbon

Date	Injection Rate, lb/MMacf	Removal Across ESP, %		Removal Across JBR FGD, %		Overall Removal Across ESP/JBR FGD, %	
		Total	Hg^o	Total	Hg^o	Total	Hg^o
3/1/04	0	48	8	53	23	75	29
	6.3	58	-	58	45	82	-
	0	26	-	68	-	76	-
3/2/04	0	53	33	24	7	64	37
	12.7	71	60	0	-36	71	45
	0	46	-	15	-	54	-
3/3/04	0	45	49	40	-7	67	45
	2.1	57	52	32	-31	70	36
	4.2	58	-	24	-	68	-
	2.1	-	-	-	-	66	-
	3.1	57	55	38	-49	73	33
	0	26	-	51	-	64	-
3/4/04	0	42	41	33	-5	61	38
	5.2	61	58	26	-37	71	42
	7.3	62	55	49	-37	81	38
	9.4	64	62	21	-43	71	45
	12.7	63	-	8	-	66	-
	0	30	-	24	-	47	-

A similar plot of total vapor-phase mercury removal across the ESP/JBR FGD system during sorbent injection tests is provided in Figure 3-10. Native removal values were generally in the range of 45 to 65 percent. A slight increase in total mercury removal across the ESP/JBR FGD system was observed during the Darco FGD activated carbon injection tests when compared to baseline. Total mercury removal values ranged from 66 to 82 percent during sorbent injection tests with the maximum value observed at an injection rate of 6.3 lb/MMacf. Native removal was also highest during the 6.3 lb/MMacf injection test at 75 percent vapor-phase.

Because the native mercury removal was quite high, the amount of mercury reduction attributed to Darco FGD™ carbon injection was estimated by calculating the percent reduction in average total vapor-phase mercury levels at the ESP outlet and Stack locations compared to average baseline levels (i.e., native levels). These percent reductions are plotted in Figures 3-11 and 3-12, respectively, for each sorbent injection test. The percent reduction in total mercury concentration for a given injection rate is calculated as follows:

$$\text{Percent Reduction} = [1 - (I / BL)] \times 100$$

Where, I = average SCEM total mercury concentration at the ESP outlet or Stack for the injection rate test period, and

BL = average SCEM total mercury concentration at the ESP outlet or Stack for the baseline test period calculated based on the concentrations measured at the beginning and end of each test day.

Both Figures 3-11 and 3-12 show that additional mercury removal from sorbent injection plateaus around 6 lb/MMacf. For the Unit 1 ESP, Figure 3-11 indicates a 20 to 45 percent reduction in total vapor-phase mercury concentrations at the ESP outlet compared to baseline concentrations over the range of sorbent injection rates tested. At the Stack, a 10 to 30 percent reduction in total vapor-phase mercury concentrations was observed compared to baseline concentrations.

It was thought that carbon injection may increase the percent mercury oxidation at the ESP outlet thereby improving mercury removal across the JBR FGD scrubber; however, data shown previously in Tables 3-3 and 3-4 indicate no increase in percent oxidation and no improvement in total vapor-phase mercury removal across the JBR scrubber between baseline and Darco FGD™ carbon injection tests. In fact, on three of the four injection test days the percent mercury oxidation at the ESP outlet location appeared to decrease slightly with increasing injection rates. Figure 3-13 shows the elemental vapor-phase mercury concentrations measured at the ESP inlet, ESP outlet and Stack locations during Darco FGD™ carbon injection tests.

3.1.4 Coal, Fly Ash, JBR FGD Byproducts, and Other Process Streams

Coal

Table 3-5 shows the analytical results for as-fired coal samples. Composite samples of the Unit 1 coal were collected twice per day downstream of the coal pulverizers and were analyzed in triplicate for mercury; an average of the triplicate analyses is reported in Table 3-5. Ultimate/proximate and chlorine analyses are also being performed on these samples, but results are not yet available. The ultimate/proximate results currently shown in Table 3-5 are for as-bunkered coal samples provided by Plant Yates.

Bottom Ash and Fly Ash

Table 3-6 shows the results for mercury and LOI analyses of the bottom ash and ESP fly ash samples. Composite fly ash samples were obtained by collecting and combining ash from each field of the ESP during the baseline characterization and sorbent injection test periods. A single grab sample of bottom ash was obtained.

There was no apparent increase in the carbon content of the ESP fly ash, as measured by percent LOI, for the Darco FGD™ activated carbon injection tests compared to the baseline tests. As shown in Figure 3-14, the mercury content of both the bottom ash and the ESP fly ash samples were directly related to the percent LOI of the ash.

Table 3-5. Unit 1 - Coal Analyses Baseline and Darco FGD™ Carbon Injection Tests

Date	**2/24**	**2/25**	**2/25**	**2/26**	**2/26**	**2/27**	**2/27**	**3/1**	**3/1**	**3/2**	**3/2**	**3/3**	**3/3**	**3/4**	**3/4**
Sample Time	**13:30**	**9:20**	**12:30**	**9:20**	**13:00**	**9:00**	**12:10**	**10:00**	**13:05**	**9:30**	**13:05**	**9:30**	**13:10**	**9:10**	**13:00**
Test Condition [a]	**BL**	**BL**	**BL**	**BL**	**BL**	**BL**	**BL**	**SI**	**SI**	**SI**	**SI**	**SI**	**SI**	**SI**	**SI**
Proximate, wt % as received [b]															
Moisture	6.67	NC	6.65	NC	7.22	-	6.5	-	-	-	-	-	NC	-	-
Ash	12.64	NC	13.27	NC	13.04	-	10.16	-	-	-	-	-	NC	-	-
Volatile Matter	28.32	NC	27.86	NC	27.4	-	28.43	-	-	-	-	-	NC	-	-
Fixed Carbon	52.38	NC	52.23	NC	52.33	-	54.90	-	-	-	-	-	NC	-	-
Ultimate, wt % as received															
Carbon	NC	NC	NC	NC	NC	-	-	-	-	-	-	-	NC	-	-
Hydrogen	NC	NC	NC	NC	NC	-	-	-	-	-	-	-	NC	-	-
Nitrogen	NC	NC	NC	NC	NC	-	-	-	-	-	-	-	NC	-	-
Sulfur [b]	0.76	NC	0.73	NC	0.91	-	1.29	-	-	-	-	-	NC	-	-
Oxygen	NC	NC		NC	NC	-	-	-	-	-	-	-	NC	-	-
Heating Value [b] (Btu/lb, as received)	12253	NC	12196	NC	12218	-	12803	-	-	-	-	-	NC	-	-
Mercury (µg/g, dry)	0.062	0.062	0.063	0.059	0.062	0.075	0.086	0.084	0.064	0.071	0.076	0.065	0.081	0.073	0.11
Mercury (lb/trillion Btu)	5.1	NC	5.2	NC	5.1	-	6.7	-	-	-	-	-	NC	-	-
Chlorine (µg/g, dry)	NC	NC	NC	NC	NC	-	-	-	-	-	-	-	NC	-	-

[a] BL = baseline characterization, SI = Darco FGD™ carbon sorbent injection

[b] Represents Plant Yates analysis of as-bunkered fuel samples. Mercury analysis was done on separate Unit 1 as-fired coal samples.

NC = sample analysis not yet completed

Table 3-6. Unit 1 – Bottom Ash and ESP Fly Ash Analyses for Baseline Characterization and Sorbent Injection Tests

Date	Time	Sample Type	Test Condition	Injection Rate (lb/MMacf)	Mercury (µg/g)	LOI (%)
2/24	13:15	ESP ash	Baseline	0	0.31	11.8
2/25	9:46	ESP ash	Baseline	0	0.26	9.9
2/25	13:10	ESP ash	Baseline	0	0.28	10.2
2/26	10:00	ESP ash	Baseline	0	0.33	12.8
2/26	13:00	Bottom Ash	Baseline	0	0.003	0.44
3/1	11:00	ESP ash	Darco FGD™ SI	6.3	0.32	12.8
3/2	13:30	ESP ash	Darco FGD™ SI	12.7	0.25	7.2
3/3	13:35	ESP ash	Darco FGD™ SI	4.2	0.27	8.5
3/4	13:30	ESP ash	Darco FGD™ SI	7.3	0.25	6.8

JBR FGD Gypsum and Additional Process Steams

Mercury analyses for the JBR gypsum, gypsum liquor, limestone, and pond water used as makeup to the JBR scrubber system are shown in Table 3-7.

Table 3-7. Unit 1 JBR FGD Byproduct Analyses for Baseline Characterization

	JBR Gypsum (µg/g)	Limestone (µg/g)	Pond Water JBR FGD Makeup (µg/l)	Gypsum Liquor (µg/l)
Date	2/26	2/26	2/26	2/26
Time	14:15	14:45	14:45	14:15
Mercury	0.17	0.020	1.2	15.1

Mercury Mass Balance

A preliminary overall mass balance for mercury was estimated based on the measured concentrations of mercury in the coal, bottom ash, ESP fly ash, JBR FGD slurry blowdown liquor and solids (gypsum), limestone, JBR FGD makeup water, and stack outlet gas on 2/26/04. As an additional data check, mass balances for mercury were computed around the boiler and the ESP as well as around the JBR. A mass balance around the ESP was not possible because the poor sampling location at the ESP inlet precluded isokinetic sampling. Therefore, particulate loading measurements were not possible.

Mass balance results for the baseline period are shown in Table 3-8. Process stream flow rates used in the mass balance calculations were estimated based on plant process data or calculated as indicated in Table 3-8. All mercury vapor concentrations listed in Table 3-8 are at actual oxygen levels. Mercury balance closure for the entire plant was 130 percent. The mass balance around the boiler/ESP system was (99%) indicating good agreement between coal mercury levels and outlet levels measured in the ESP fly ash and ESP outlet flue gas (SCEM). However, the balance around the JBR was 180%, which increased the uncertainty in the overall balance. The estimated mercury rates exiting in the slurry blowdown appear high. The pond water recycle flow rate was estimated as the difference between the required saturation water rate and the measured makeup water flow rate. This estimation may introduce additional error into the mass balance around the JBR. This preliminary mass balance indicates that approximately 60 percent of the mercury input with the coal was captured in the ESP fly ash.

3.1.5 Additional Flue Gas Characterization Data for Unit 1

Additional flue gas characterization data were collected during the initial 2-day baseline characterization test period. These measurements included Method 26A for HCl and particulate loading measurements. In addition, particulate loading measurements were conducted at the ESP outlet during the Darco FGD™ activated carbon sorbent injection test periods to evaluate potential carbon breakthrough across the ESP. However, the Method 17 particulate results are not yet available. Results are summarized below.

Method 26A

Measured flue gas concentrations of HCl and Cl_2 in the ESP inlet and ESP outlet are summarized in Table 3-9.

Table 3-8. Unit 1 – Mercury Mass Balance Results for Baseline Characterization on 2/26/04

Stream	Flow Rate	Mercury Concentration[c]	Mercury Rate (g/hr)
Coal [a]	100,520 wet lb/hr	0.0604 dry µg/g	2.553
Bottom Ash [a]	2,622 lb/hr	0.003 µg/g	0.004
ESP Outlet Vapor [a] (SCEM)	8,472 dry Nm^3/min	1.86 µg/ Nm^3	0.946
ESP Outlet Particulate [a] (OH)	8,472 dry Nm^3/min	0.008 µg/Nm^3	0.004
ESP Captured Fly Ash [a]	10,420 lb/hr	0.331 µg/g	1.564
Limestone [ae]	3,133 lb/hr	0.02 µg/g	0.028
Pond Water Recycle [a]	90 gpm	1.17 µg/L	0.024
Slurry Blowdown – Liquid [b]	136 gpm	15.07 µg/L	0.449
Slurry Blowdown – Solids [b]	5,964 lb/hr	0.166 µg/g	0.449
Stack Vapor [b] (SCEM)	9,170 dry Nm^3/min	1.63 µg/Nm^3	0.897
Mass Balance Around Boiler and ESP			
		Boiler/ESP In	2.553
		Boiler/ESP Out	2.517
		Closure [d]	99 %
Mass Balance Around JBR FGD System			
		JBR FGD In	1.002
		JBR FGD Out	1.795
		Closure [d]	179%
Overall Mass Balance			
		Total In	2.605
		Total Out	3.3362
		Closure [d]	**129%**

[a] Estimated stream flow rate
[b] Measured stream flow rate
[c] Mercury vapor concentrations at the actual flue gas oxygen content.
[d] Closure (%) = (Out/In) x 100

Table 3-9. Units 1 - Method 26A Data for Baseline Characterization Tests

Location	Date/Time (EST)	HCl (ppmv)	Cl_2 (ppmv)
ESP Inlet	2/25/04 10:25 – 11:36	10.9	0.044
	2/25/04 12:02 – 13:05	10.9	0.025
	2/25/04 14:18 – 15:18	10.1	<0.01
	2/25/04 15:37 – 16:37	10.7	<0.01
	2/25/04 17:00 – 18:00	12.9	<0.01
	Average	**11.1**	**0.02**
ESP Outlet	2/25/04 10:25 – 11:36	10.7	0.021
	2/25/04 12:21 – 16:45	9.4	0.042
	2/25/04 15:45 – 16:45	9.4	<0.01
	2/25/04 17:00 – 18:00	12.5	<0.01
	Average	**10.5**	**0.02**

Particulate Loading

Particulate loading measurements for the Method 26A tests are summarized in Table 3-10.

Table 3-10. Units 1 – Particulate Loading Measurements for Baseline and Darco FGD™ Activated Carbon Sorbent Injection Tests

	2/25/04	2/25/04	2/25/04	2/25/04
Sample Time	10:25 – 11:36	12:21 – 16:45	15:45 – 16:45	17:00 – 18:00
Test Method	Method 26a	Method 26a	Method 26a	Method 26a
Injection Rate (lb/MMacf)	0	0	0	0
ESP Outlet Loading (mg/Nm^3)	51	66	44	90

3.2 Unit 2 Parametric Testing

Baseline and parametric testing of Unit 2 during injection of the Darco FGD™ activated carbon sorbent was conducted during the weeks of March 15th and March 22nd. Tests were conducted with the dual flue gas conditioning system both on and off to observe the effects on mercury speciation, removal, and ESP performance during sorbent injection. Test conditions are discussed in the following sections; however, laboratory results are not yet available for some of the samples collected during this test effort. Currently available test results are included below, and the remaining data will be presented and discussed in the next quarterly report.

3.2.1 Test Conditions and Modifications to Test Plan

Field test conditions for the Unit 2 baseline and Darco FGD™ activated carbon parametric tests are summarized below in Table 3-11. All sampling activities were completed as planned. Comprehensive baseline characterization of the Unit 2 system was conducted on 3/17/04 through 3/19/04; sorbent injection tests were conducted on 3/22/04 through 3/26/04.

Sorbent injection rates for the tests were selected based on the results of the Unit 1 Darco FGD™ sorbent injection tests. Tests were conducted using Darco FGD™ carbon injection rates ranging from approximately 2.3 to 12.7 lb/MMacf (60 to 365 lb/hr), with the NH_3/SO_3 flue gas conditioning system both on and off. Because of concerns about potentially excessive arc rates in the ESP, the lowest sorbent injection rate test with the conditioning system on was conducted first, with incrementally higher injection rates tested on subsequent days. Tests on Day 6 were

Table 3-11. Field Test Conditions for the Unit 2 Darco FGD™ Carbon Parametric Tests

Date	Baseline, Full Load			Darco FGD™ Carbon Injection, Full Load												
	Day 1	**Day 2**	**Day 3**	**Day 4**		**Day 5**			**Day 6**				**Day 7**			
	3/17/04	**3/18/04**	**3/19/04**	**3/22/04**		**3/24/04**			**3/25/04**				**3/26/04**			
Sorbent Injection Time Period (EST)	NA	NA	NA	11:45 – 15:25	15:25 – 16:30	13:25 – 16:11	16:11 – 17:14	17:14 – 18:11	9:57 – 13:11	13:11 – 16:00	16:00 – 17:30	17:30 – 18:14	9:57 – 12:46	12:46 – 14:30	14:30 – 15:40	15:40 – 16:15
Sorbent Injection Rate (lb/MMacf)	0	0	0	2.1	4.2	6.3	8.3	12.7	2.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Sorbent Injection Rate (lb/hr)	0	0	0	60	120	180	240	365	60	120	120	120	120	120	120	120
Dual Flue Gas Injection (NH_3 ppmv/SO_3 ppmv)	6/10	6/10	6/10	6/10	6/10	6/10	6/10	6/10	0/0	0/0	3/5	0/0	6/10	3/5	6/10	2/10

conducted at low- and mid-level sorbent injection rates while the flue gas conditioning system was turned off. For the final set of tests, the ammonia and SO_3 injection rate was varied while the sorbent injection rate was held constant at 120 lb/hr.

3.2.2 Mercury Speciation and Removal

Baseline Characterization

Average mercury concentrations from the SCEM analyzer for the Unit 2 air heater outlet (ESP inlet) and ESP outlet locations during the full-load baseline test period are summarized in Table 3-12. Average SCEM mercury concentrations are reported in Table 3-12 for the corresponding Ontario Hydro source sampling test periods on 3/18/04; however, Ontario Hydro results are not yet available for comparison. For these baseline tests, the dual flue gas conditioning system was turned on with operating set-points of approximately 6 ppm NH_3 and 10 ppm SO_3 (i.e., "Full" condition). Based on the SCEM data, average total vapor-phase mercury removal across the ESP on 3/18/04 was 36 percent compared to 34 percent for the Unit 1 ESP system during baseline conditions. An increase in mercury oxidation was observed across the Unit 2 ESP (from 35% to 48%); whereas, a decrease in percent mercury oxidation was observed across the Unit 1 ESP (from 51% to 37%).

Total and elemental vapor-phase mercury concentrations, as measured by the SCEM, are shown for each sample location over the entire baseline characterization period in Figure 3-15 to illustrate variability in the mercury concentrations and speciation over time.

Sorbent Injection with Darco FGD™ Activated Carbon

Table 3-13 provides the average SCEM mercury measurement data obtained during the various Darco FGD™ carbon sorbent injection test periods.

To illustrate the additional reduction in total vapor-phase mercury removal concentrations attributed to sorbent injection (i.e., reduction beyond native levels), the percent reduction in average total vapor-phase mercury at the ESP outlet relative to average baseline levels (i.e., native levels) are plotted in Figure 3-16, for each sorbent injection test condition. The calculations for percent reduction in total vapor-phase mercury are the same as for Unit 1.

These short-term test data indicate an additional 30 to 40 percent reduction in total vapor-phase mercury was achieved at an injection rate of 2 lb/MMacf. No additional reduction was observed at higher injection rates up to 13 lb/MMacf. Figure 3-16 also indicates the set points for the dual flue gas conditioning system during each test period. The dual flue gas conditioning system had no effect on total vapor-phase mercury reduction at the ESP outlet.

A plot of total vapor-phase mercury removal across the ESP system during sorbent injection tests is provided in Figure 3-17 to illustrate overall mercury removal. Here, removal is calculated based on the simultaneous average SCEM vapor-phase total mercury concentrations obtained at the ESP inlet and ESP outlet locations. Native removals across the ESP ranged from 20 to as high as 66 percent, with the majority of values for non-injection periods concentrated between 20 and 30 percent. These removals compare favorably the value of 36 percent removal measured during the week of baseline characterization.

Native removals of 56 and 66% were measured during the morning and afternoon of one single test day (3/24/04). These native removals were higher than native removals during the rest of the week. As shown in Figure 3-14, the mercury content (0.52 μg/g) and percent LOI (21.5%) for the ESP ash sample collected during the daily baseline test period on 3/24/04 were also the highest values measured during the Unit 2 tests and tend to support the higher native removals observed on this day. The highest injection rates were also tested on the day of the highest native removal.

For the ESP system, the removal curve flattens out near 70 percent for sorbent injection rates of 6 lb/MMacf and above. For a given test day, approximately 10 to 30 percent additional removal of total vapor-phase mercury was observed across the ESP compared to the native baseline removals. Total vapor-phase mercury removal across the ESP at the highest injection rate of 12.7 lb/MMacf was 73 percent. These results are similar to the removal seen across the Unit 1 ESP.

3.2.3 Additional Data

Aside from the ESP fly ash results referenced above, additional analytical data for coal, ESP fly ash, and flue gas characterization samples as well as plant process data are not currently available for the Unit 2 baseline and parametric tests. These data will be presented and discussed in the next quarterly report.

Table 3-12. Unit 2 - Average SCEM Mercury Measurements During Baseline Characterization on 3/18/04, NH_3/SO_3 Conditioning System On

Run No.	Sampling Period (EST)	Vapor Phase			
		Elemental	Oxidized	Percent Oxidized	Total
		ESP Inlet, µg/Nm³			
1	9:15-11:15	4.37	2.16	33	6.54
2	12:15-14:15	3.88	2.11	35	5.99
3	15:40-17:040	3.65	1.95	35	5.60
Avg		3.97	2.08	35	6.04
		ESP Outlet, µg/Nm³			
1	9:15-11:22	1.77	1.58	47	3.35
2	12:15-14:15	2.18	1.93	47	4.11
3	15:40-17:040	2.16	2.07	49	4.22
Avg		2.04	1.86	48	3.89
		Removal, %			
Avg		49	11	NA	36

Note: All data normalized to 3% oxygen. Vapor phase oxidized mercury for the SCEM was computed as the difference between the total and elemental measurements.

NA = Not applicable.

NC = Analysis not yet completed.

Table 3-13. Unit 2 - Average SCEM Mercury Measured for Injection Tests of Darco FGD™ Activated Carbon

Date	Injection Rate (lb/MMacf)	Conditioning [a]	ESP Inlet, μg/Nm³			ESP Outlet, μg/Nm³			Total Hg Removal Across ESP, %
			Total	Hg^o	% Oxidized	Total	Hg^o	% Oxidized	
3/22/04	0	Full	7.1	2.4	67	5.3	2.1	60	25
	2.1	Full	-	-	-	3.7	1.8	52	48[b]
	4.2	Full	-	-	-	2.9	1.6	45	50[b]
	0	Full	5.7	-	-	4.6	-	-	19
3/24/04	0	Full	6.3	-	-	2.8	-	-	56
	6.3	Full	6.6	-	-	2.0	-	-	70
	8.3	Full	6.6	3.9	41	2.0	-	-	70
	12.7	Full	6.7	4.3	37	1.8	-	-	73
	0	Full	6.8	-	-	2.3	-	-	66
3/25/04	0	None	7.5	4.4	42	5.2	2.4	54	31
	2.1	None	6.4	4.2	34	3.4	-	-	47
	4.2	None	6.2	4.0	36	3.3	-	-	47
	4.2	Half	6.6	4.0	39	3.3	2.1	37	50
	4.2	None	6.5	-	-	3.5	-	-	46
	0	None	-	3.9	-	3.9	-	-	-
3/26/04	0	Full	5.4	-	-	4.3	1.9	56	20
	4.2	Full	5.5	3.4	37	2.7	-	-	51
	4.2	Half	4.8	-	-	2.6	-	-	46
	4.2	Full	4.7	2.9	39	2.6	-	-	45
	4.2	Low NH_3	-	3.1	-	2.7	-	-	43[b]
	0	Full	4.6	-	-	3.7	-	-	20

Note: All concentrations normalized to 3% oxygen.

[a] Full = 6 ppm HN_3, 10 ppm SO_3
Half = 3 ppm HN_3, 5 ppm SO_3
Low NH_3 = 2 ppm HN_3, 10 ppm SO_3
None = 0 ppm HN_3, 0 ppm SO_3

[b] The corresponding ESP inlet concentration was not available. Removal was calculated based on the nearest ESP inlet measurement.

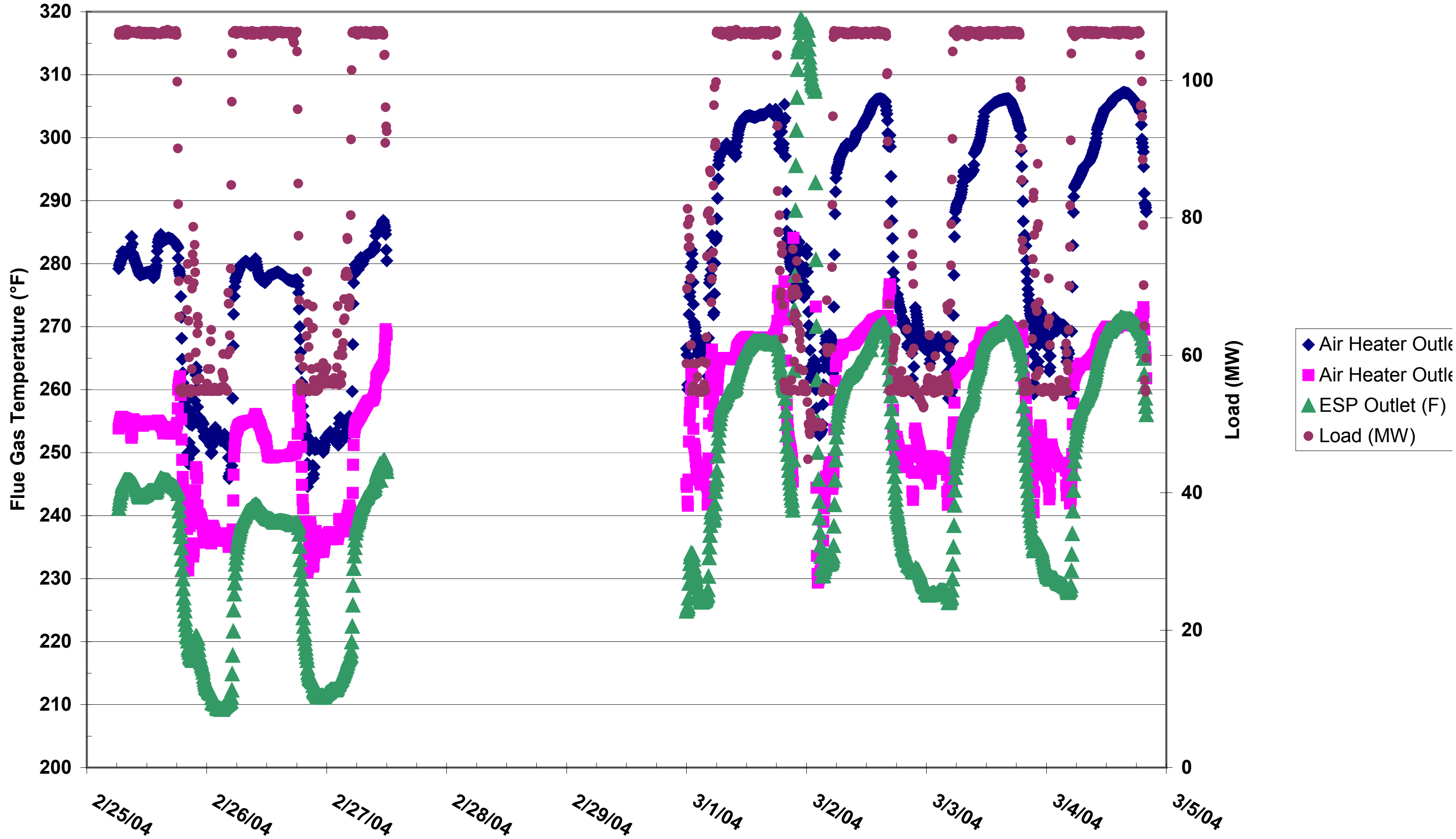

Figure 3-1. Unit 1 Air Heater Outlet and ESP Outlet Flue Gas Temperature During Baseline and Darco FGD™ Carbon Injection Tests

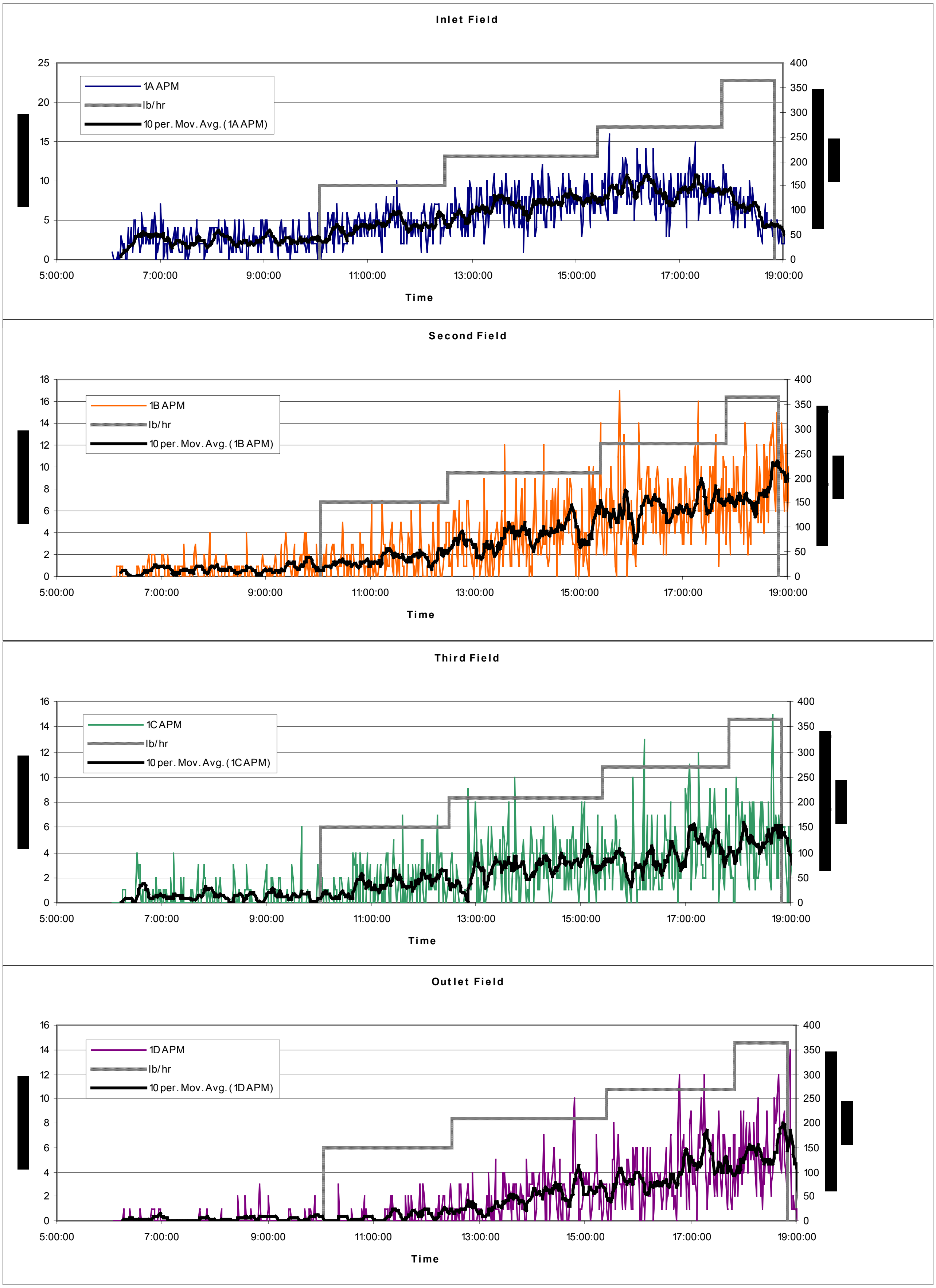

Figure 3-2. Unit 1 ESP Arc Rate by Field for Parametric Carbon Injection Tests Conducted on 3/4/04

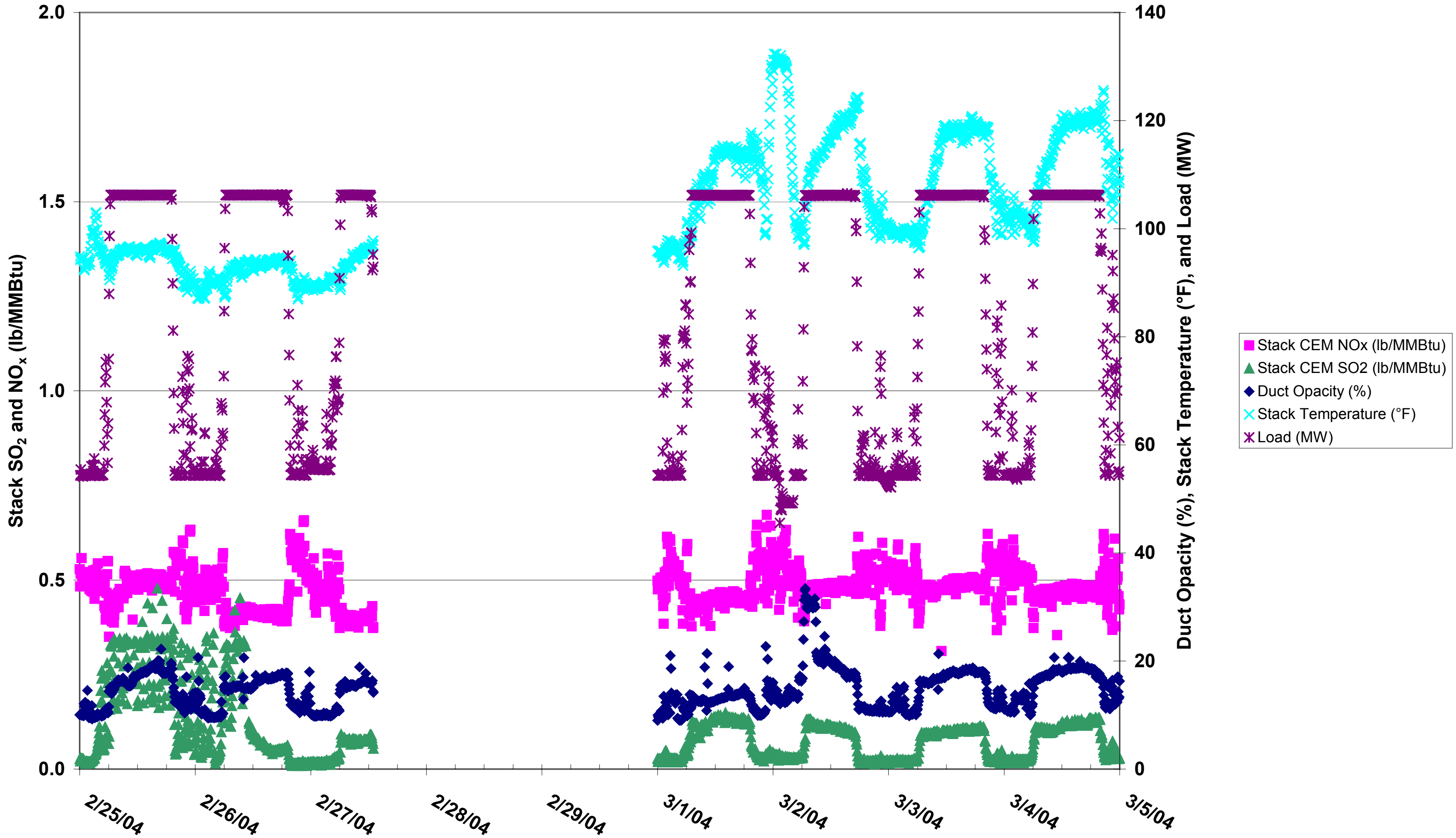

Figure 3-3. Unit 1 CEM Data During Baseline and Darco FGD™ Carbon Sorbent Injection

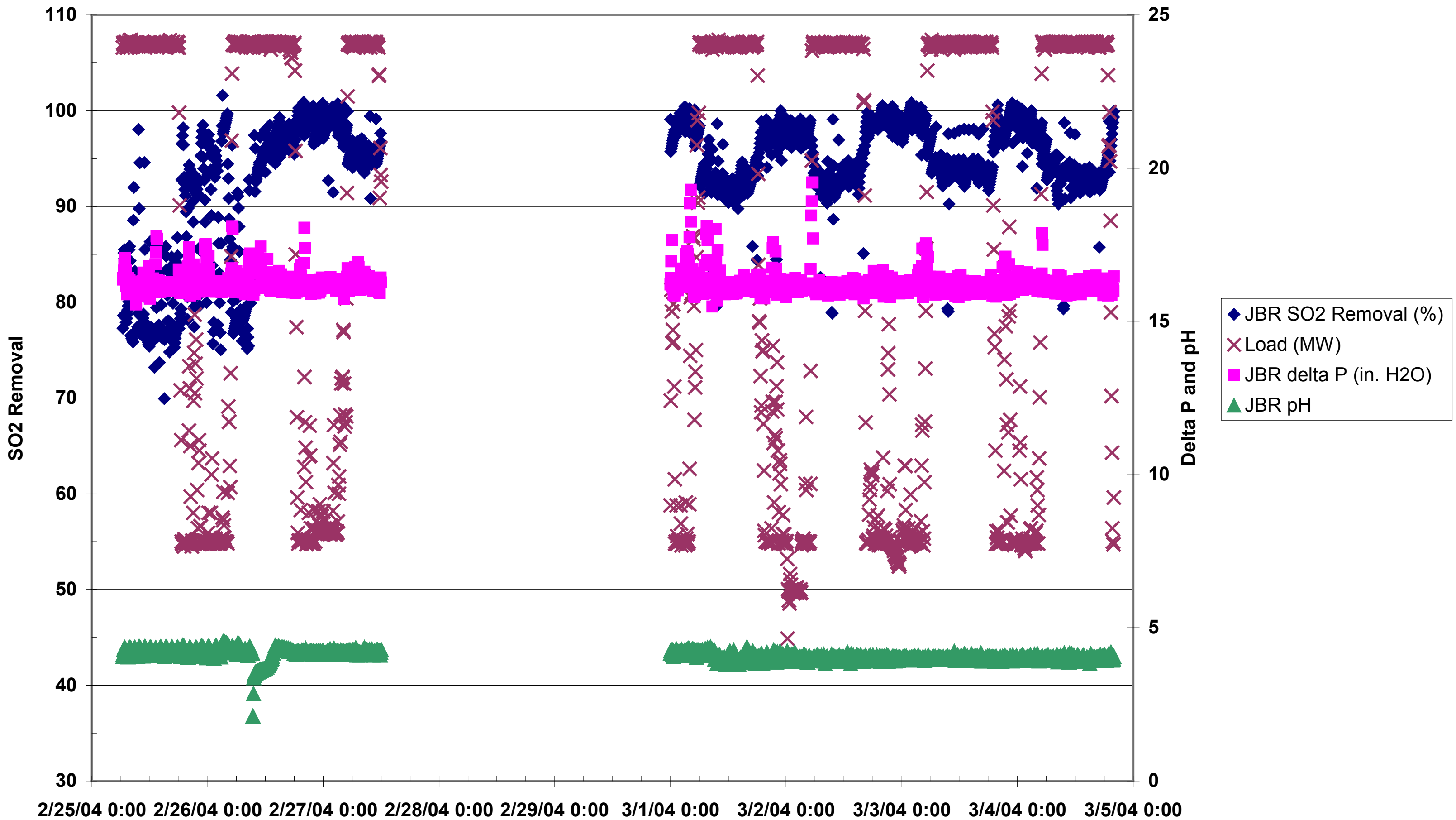

Figure 3-4. Unit 1 JBR Scrubber Process Data During Baseline and Darco FGD™ Carbon Sorbent Injection

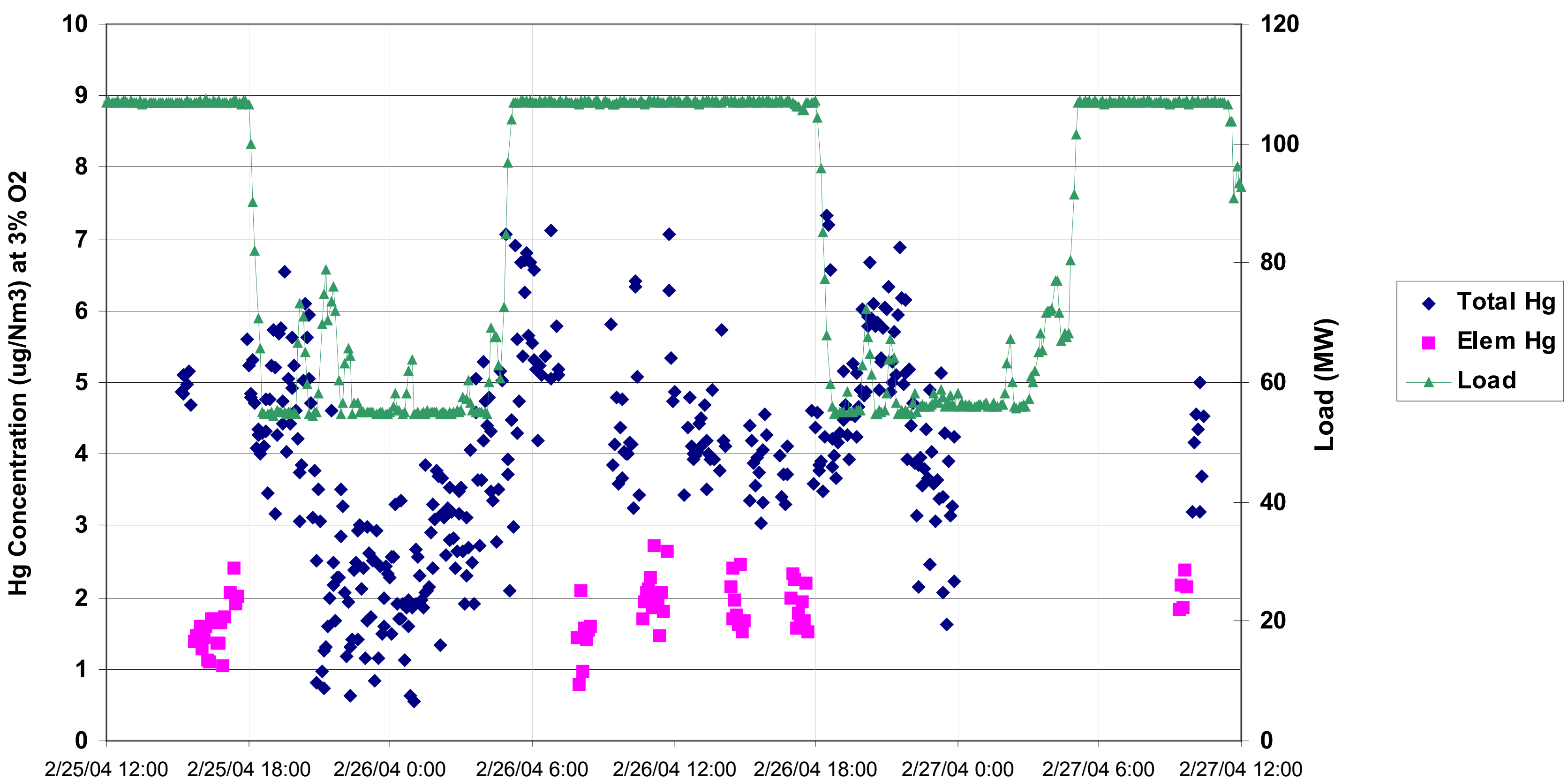

Figure 3-5. Unit 1 – SCEM Mercury Measurements at the ESP Inlet for the Baseline Characterization Test Periods

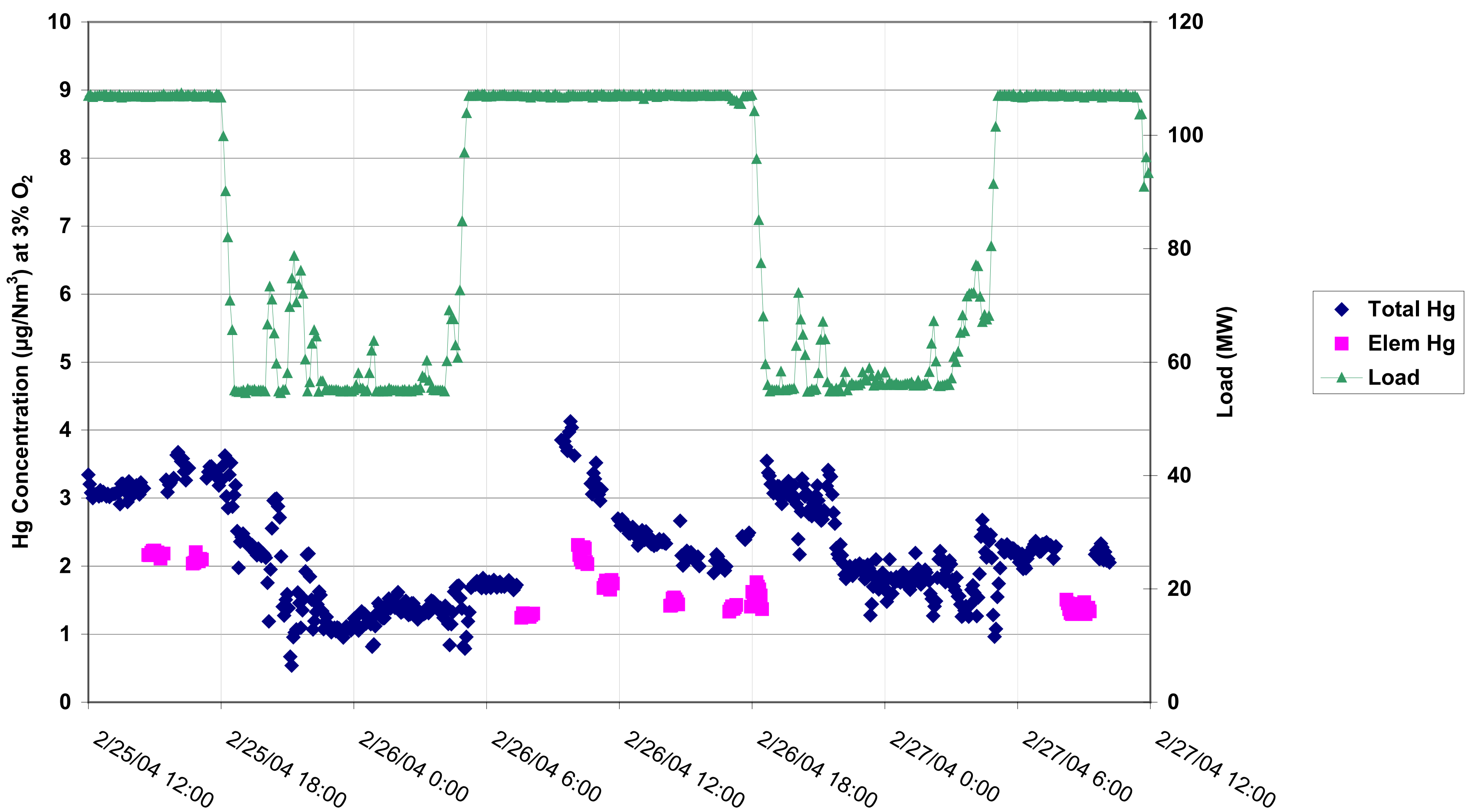

Figure 3-6. Unit 1 – SCEM Mercury Measurements at the ESP Outlet for the Baseline Characterization Test Periods

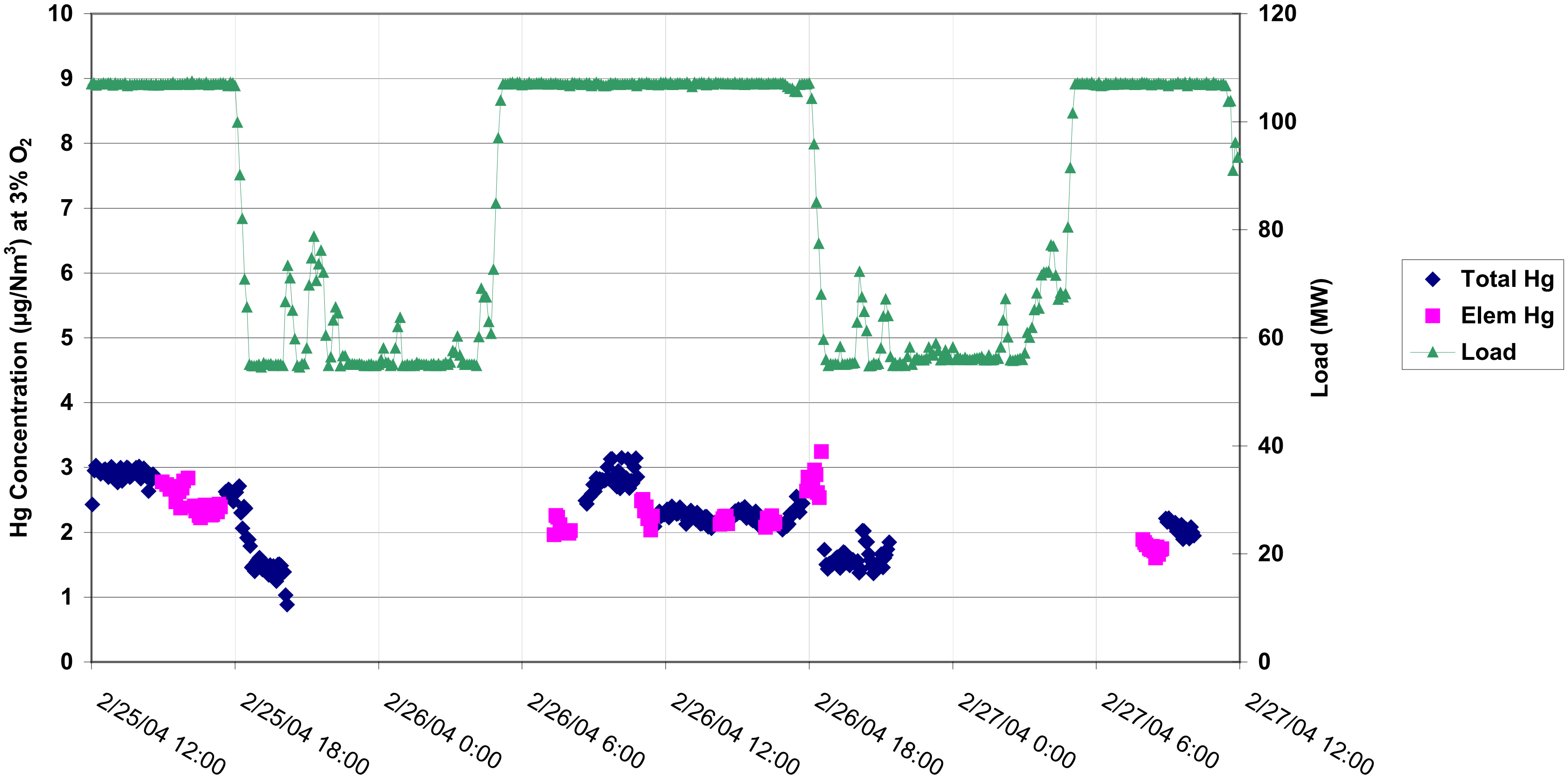

Figure 3-7. Unit 1 – SCEM Mercury Measurements at the Stack for the Baseline Characterization Test Periods

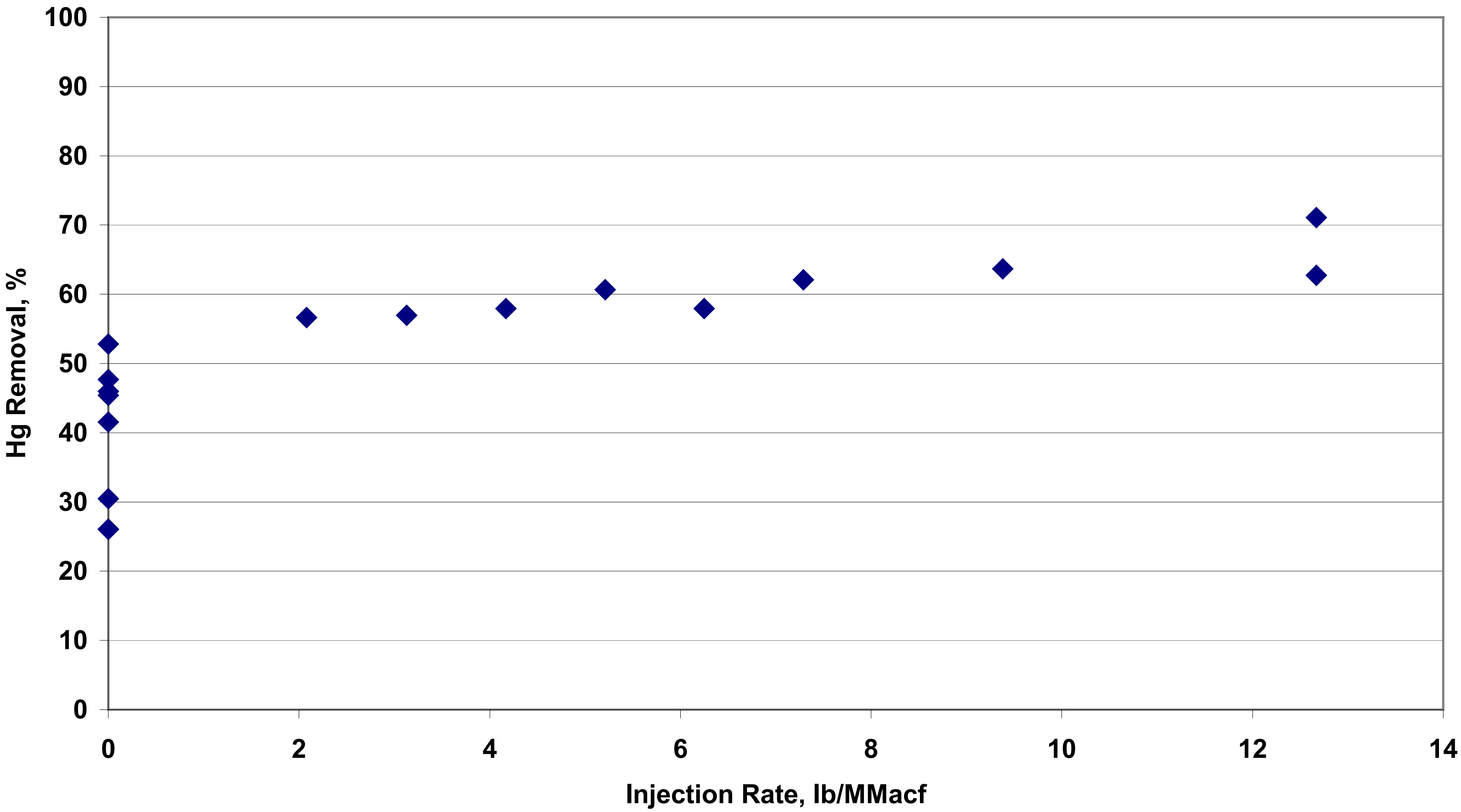

Figure 3-8. Unit 1 - ESP Vapor-Phase Mercury Removal as a Function of Sorbent Injection Rate for Darco FGD™ Activated Carbon Injection Tests

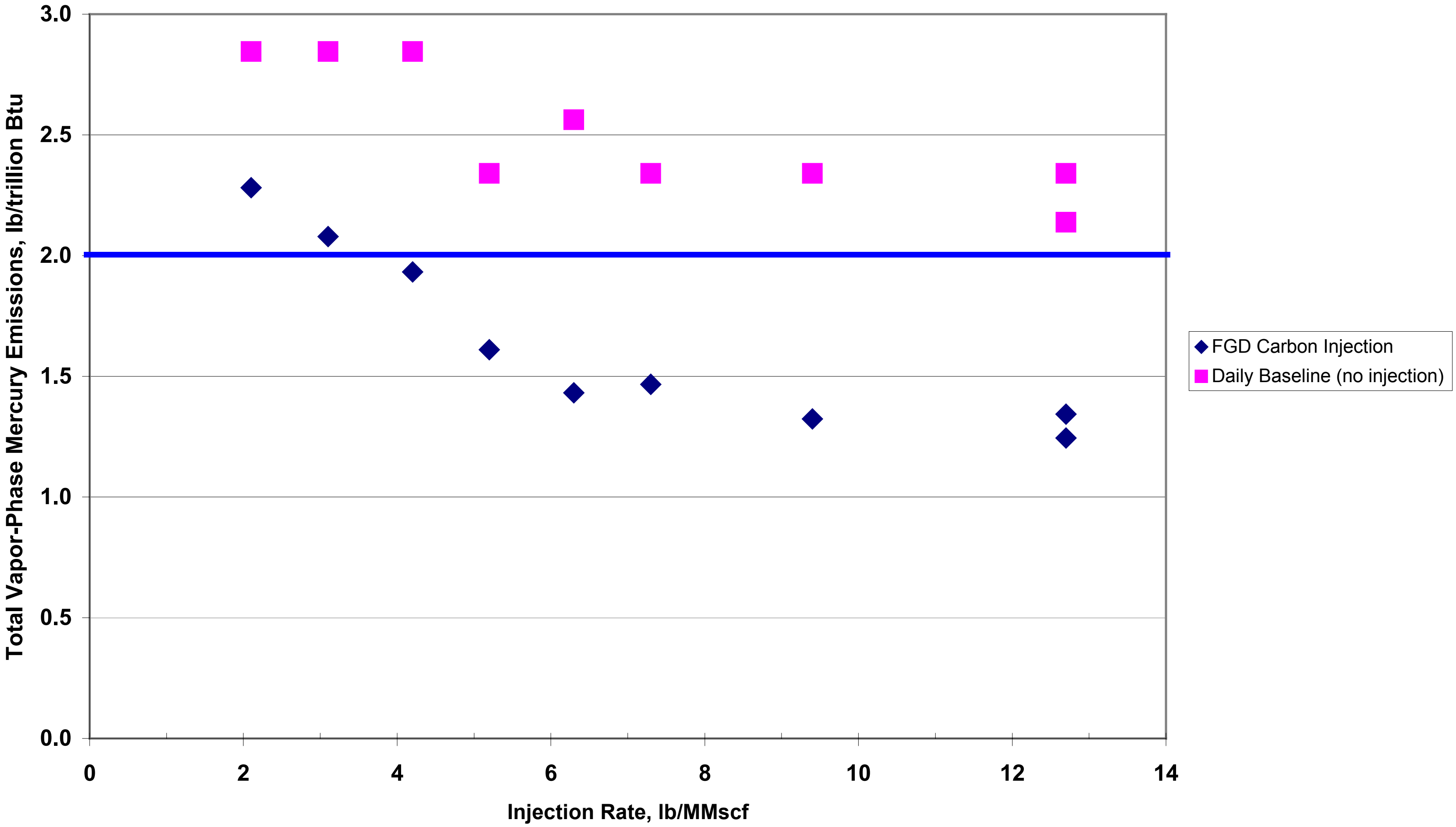

Figure 3-9. Unit 1 – ESP Outlet Vapor-Phase Mercury Emissions as a Function of Sorbent Injection Rate for Darco FGD™ Activated Carbon

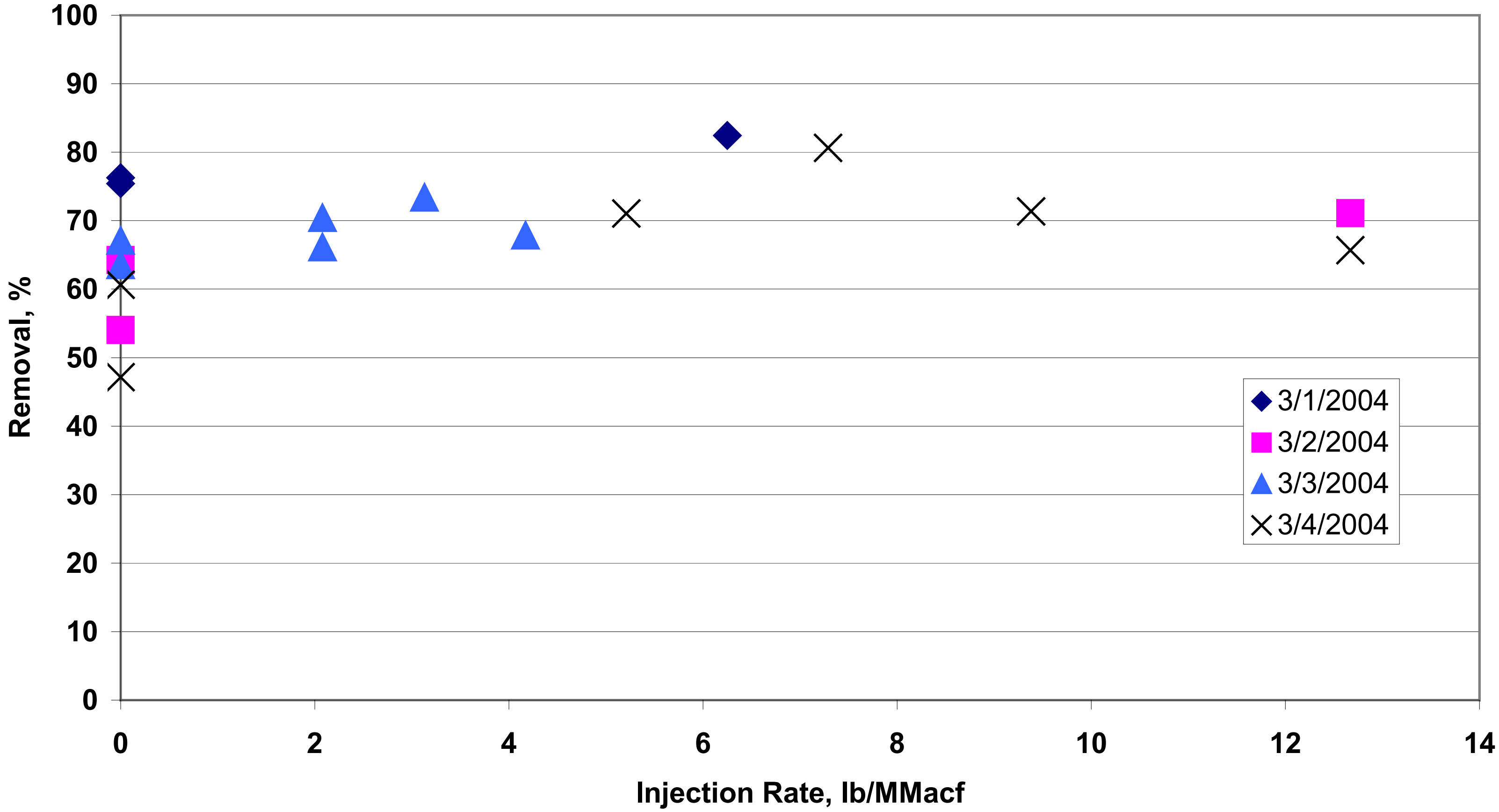

Figure 3-10. Unit 1 – Overall Vapor-Phase Mercury Removal Across ESP/JBR FGD as a Function of Sorbent Injection Rate for Darco FGD™ Activated Carbon Tests

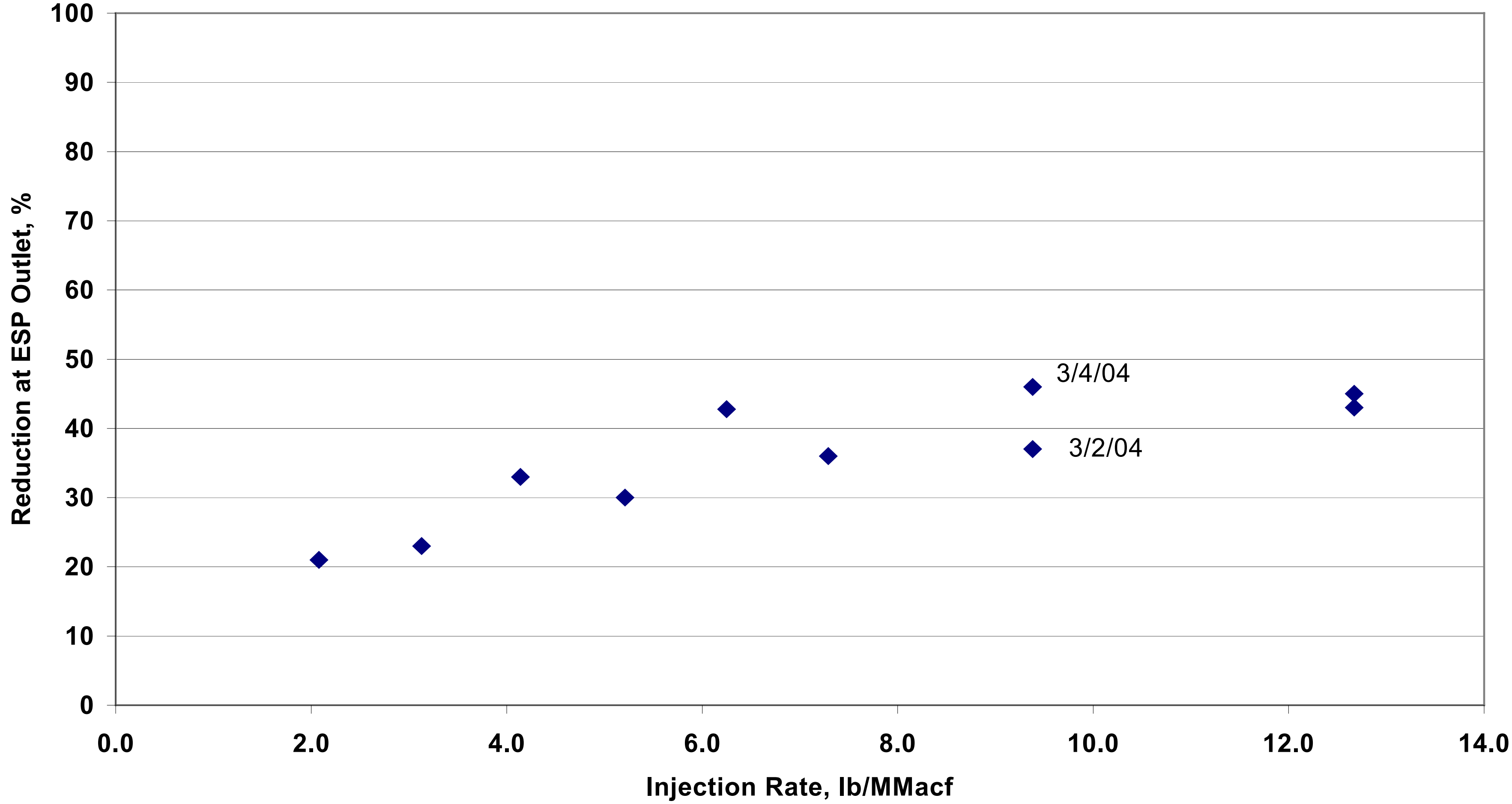

Figure 3-11. Unit 1 - Percent Reduction in Total Vapor-Phase Mercury Concentration at the ESP Outlet Relative to Baseline During FGD™ Carbon Injection

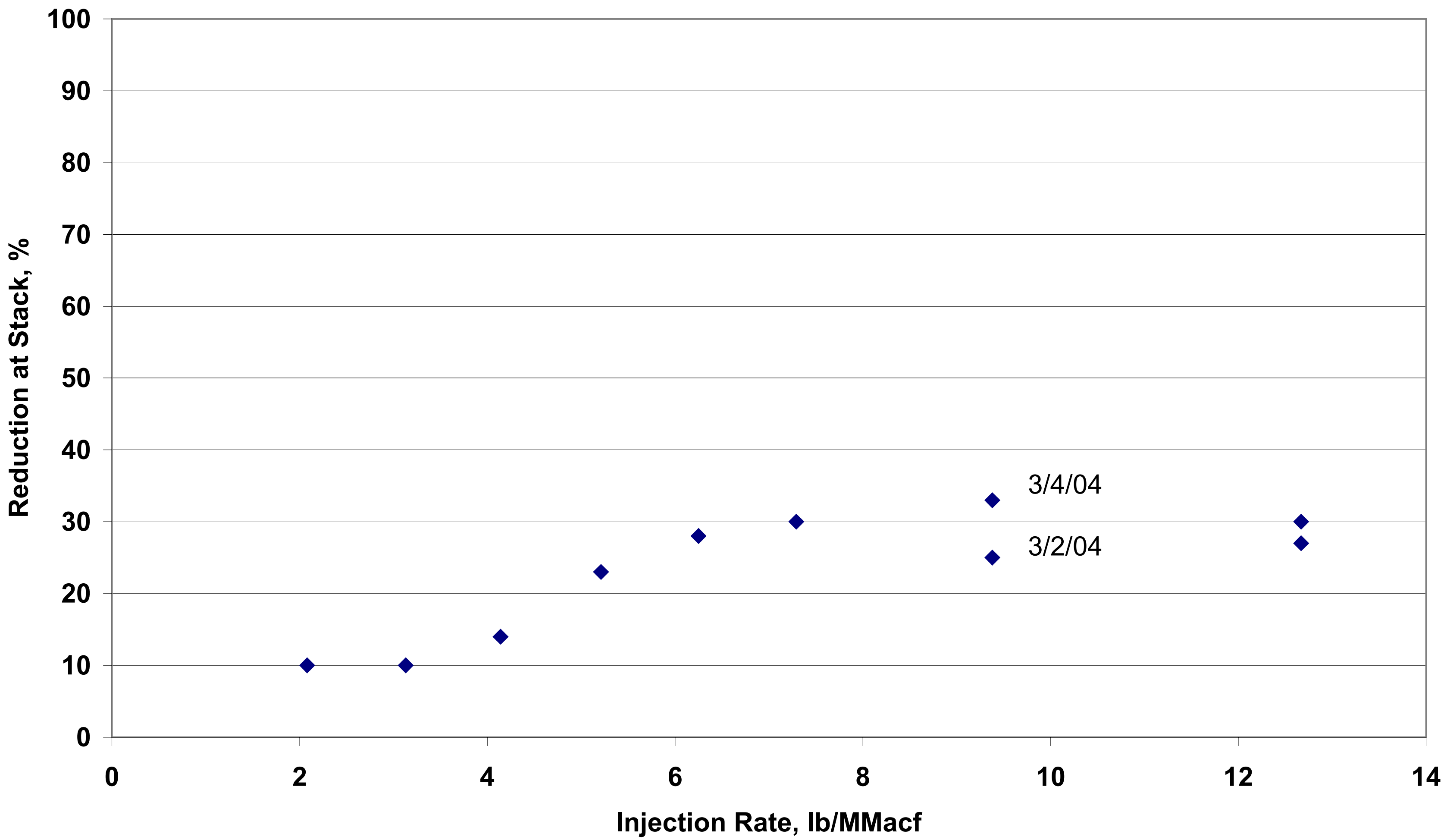

Figure 3-12. Unit 1 - Percent Reduction in Total Vapor-Phase Mercury Concentration at the Stack Relative to Baseline During FGD™ Carbon Injection

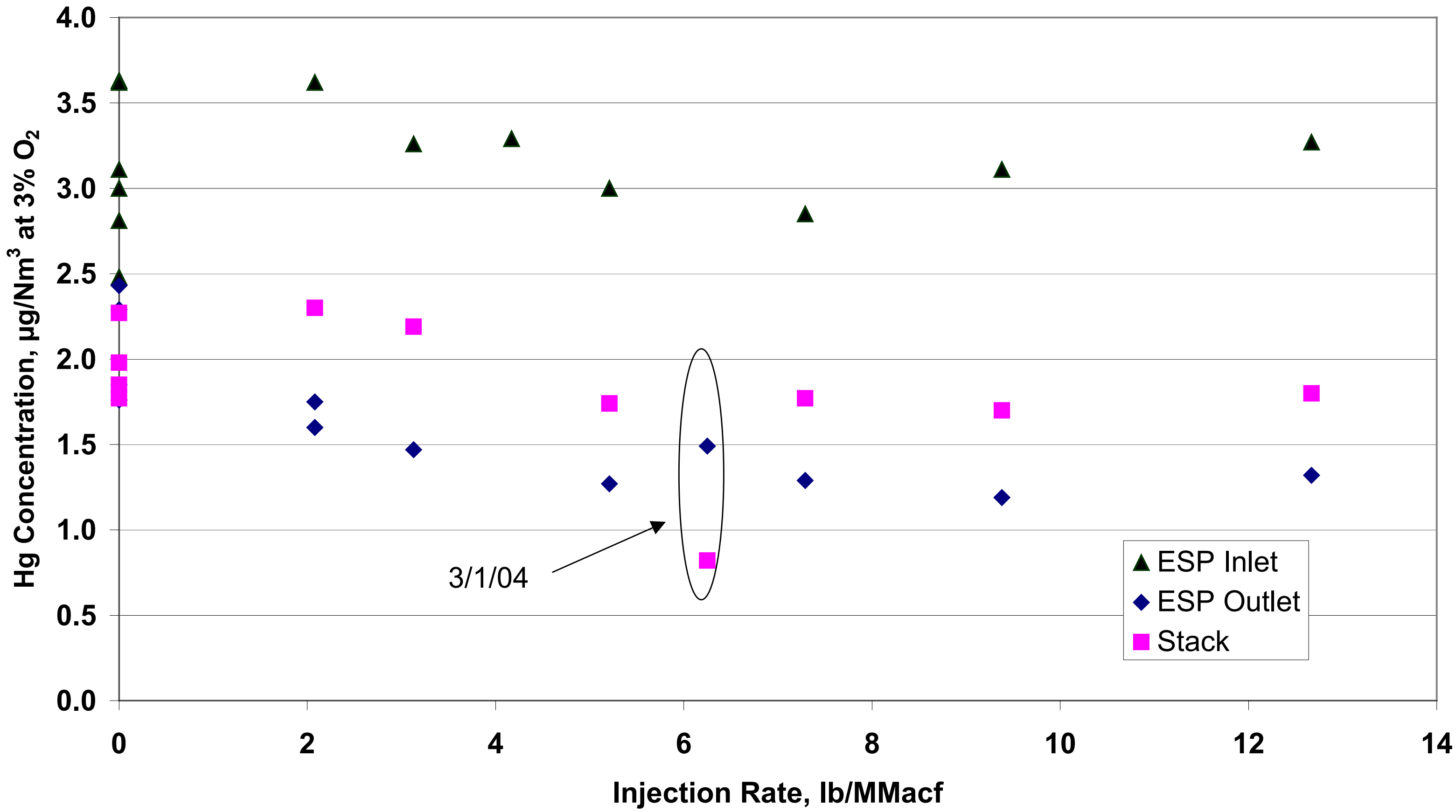

Figure 3-13. Unit 1 – Average SCEM Elemental Mercury Concentrations During Darco FGD™ Carbon Injection Tests

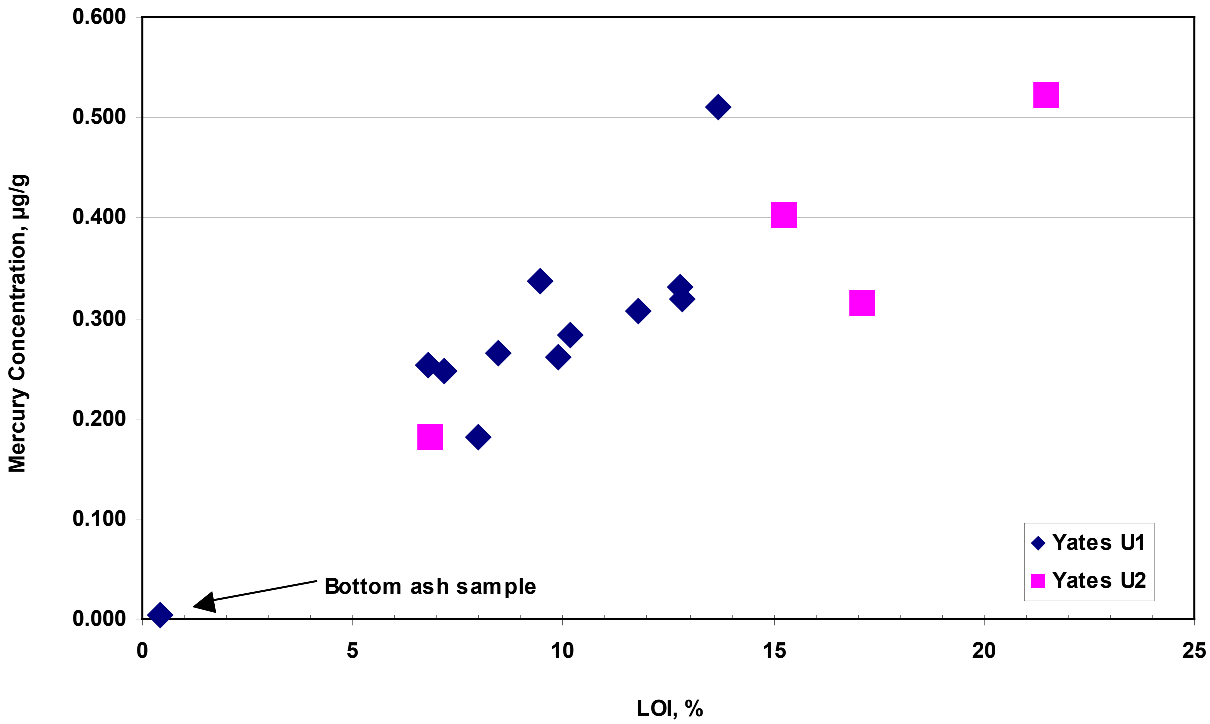

Figure 3-14. LOI and Mercury Content of Bottom Ash and ESP Fly Ash Samples

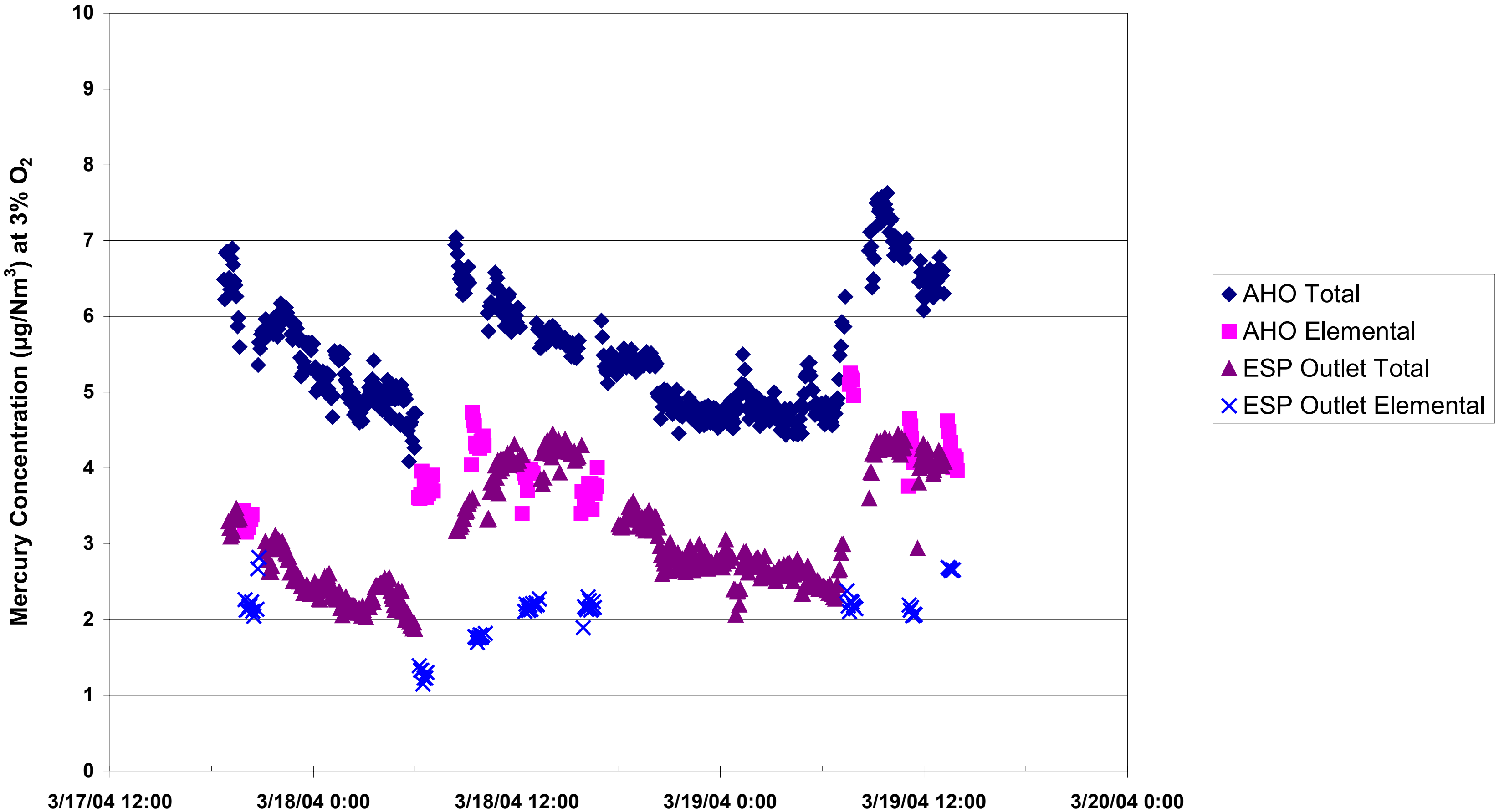

Figure 3-15. Unit 2 - SCEM Vapor-phase Mercury Concentrations for the Baseline Test Period by Sample Location

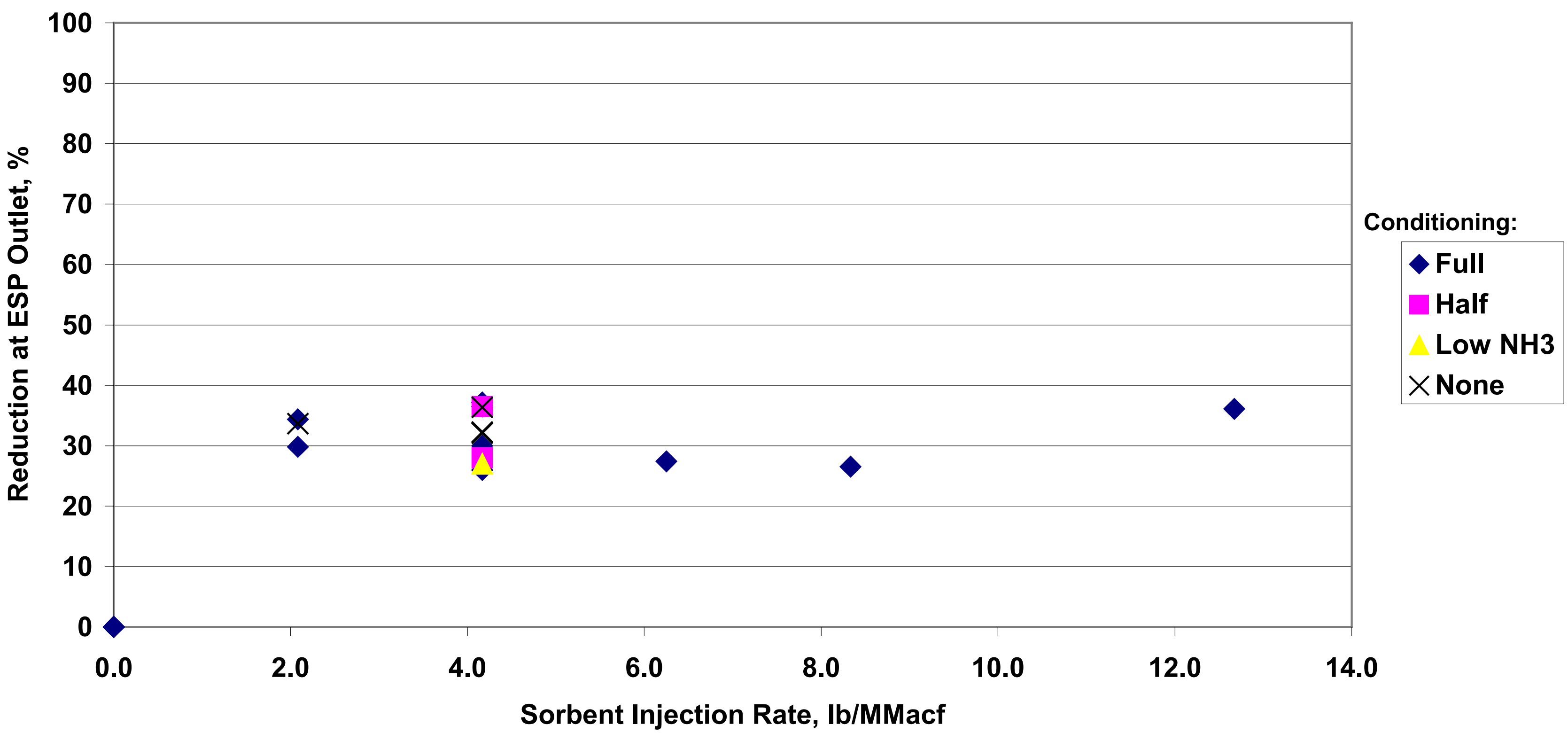

Figure 3-16. Unit 2 – Reduction in Total Vapor-phase Mercury at the ESP Outlet Relative to Baseline During Darco FGD™ Carbon Injection

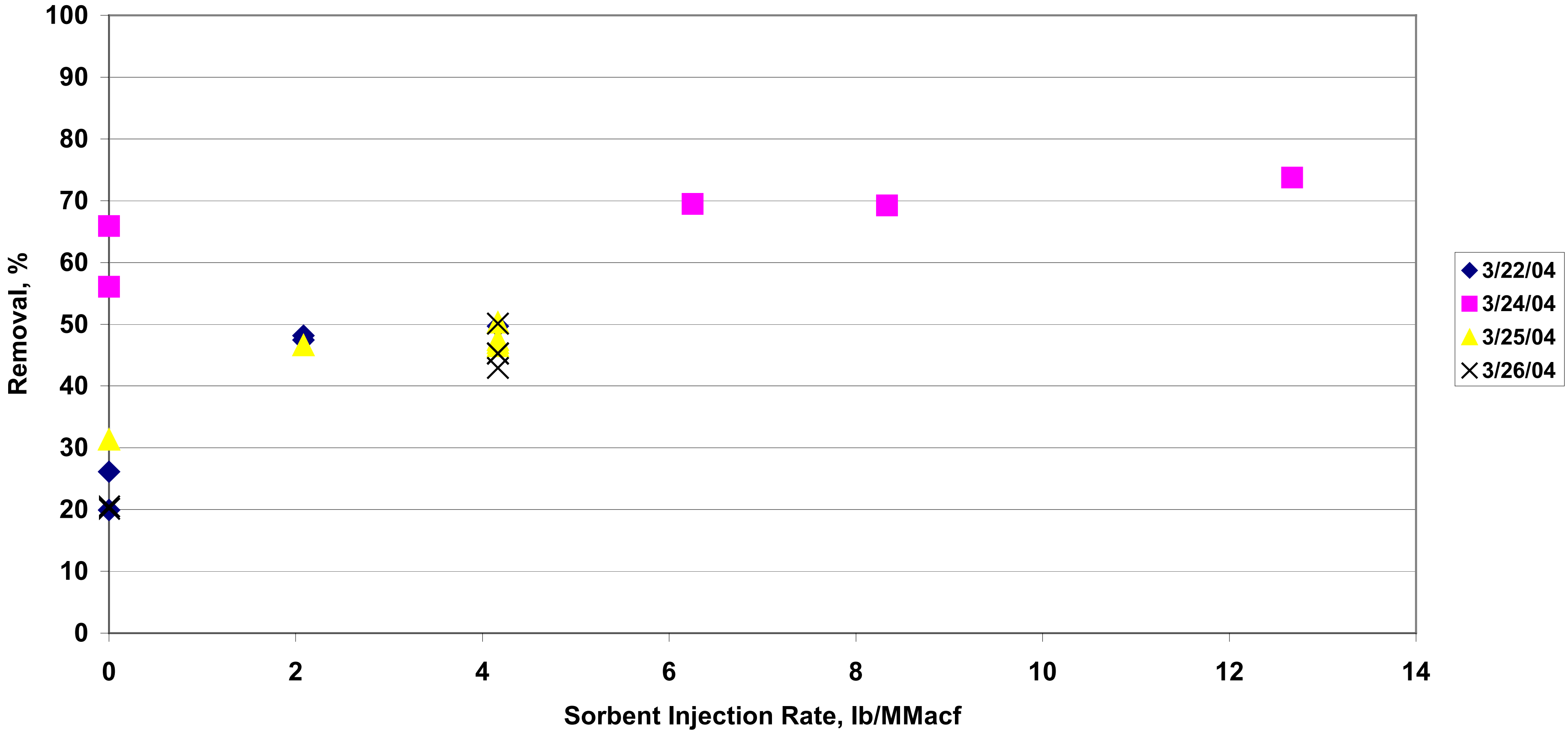

Figure 3-17. Unit 2 –Total Vapor-phase Mercury Removal Across the ESP for Darco FGD™ Activated Carbon Injection Tests

4.0 Conclusions

Currently available results from tests conducted during this quarter support the following conclusions:

Unit 1 ESP and JBR FGD System

- Injection of the benchmark Darco FGD™ activated carbon upstream of the Unit 1 ESP (SCA = 173 ft^2/1000 acfm) resulted in total vapor-phase mercury removals across the ESP ranging from 57 to 71 percent at injection rates ranging from 2.3 to 12.7 lb/MMacf.
- Native removal of total vapor-phase mercury across the Unit 1 ESP ranged from 20 to 50 percent during the various baseline measurement test periods.
- Baseline total vapor-phase mercury emissions at the Unit 1 ESP outlet were between 2.1 lb/trillion Btu and 2.9 lb/trillion Btu. Injection of Darco FGD™ activated carbon upstream of the Unit 1 ESP reduced vapor-phase mercury emission below 2 lb/trillion Btu at injection rates greater than 4 lb/MMacf.
- Injection of Darco FGD™ activated carbon upstream of the Unit 1 ESP resulted in a significant increase in the arc rate in all fields of the ESP. Arc rates increased with increasing sorbent injection rate. Arc rates of 0 to 1 arcs per minute (apm) were typically observed for the Unit 1 ESP system without carbon injection; however, rates of 10 apm and higher were observed during the Darco FGD carbon injection tests.
- The mercury content of the Unit 1 ESP fly ash increased with increasing LOI during both baseline and Darco FGD™ carbon injection tests. LOI in the ESP ash ranged from 7 to 13% during the baseline and carbon sorbent injection tests.
- For the combined ESP/JBR FGD system, removal of total vapor-phase mercury leveled off at approximately 70-80 percent at an injection rate of approximately 3 lb/MMacf and little additional removal of total mercury was observed at higher injection rates. The highest removal of 82 percent was observed at an injection rate of 6.3 lb/MMacf.
- Injection of Darco FGD™ activated carbon on Unit 1 vapor-phase did not increase the percent mercury oxidation at the ESP outlet and did not appear to improve vapor-phase mercury removal across the JBR FGD scrubber.
- The concentrations of total vapor-phase mercury in the Unit 1 ESP inlet flue gas, as measured by the SCEM, varied as a function of load, presumably due to fluctuations in flue gas temperatures and/or changes in the LOI characteristics of the fly ash. Total vapor-phase mercury concentrations were approximately two times higher during full-load conditions compared to the 50-percent load conditions during the overnight hours. This variation in flue gas mercury levels with load at the ESP inlet

may have implications for the long-term sorbent injection tests planned for Unit 1 since, unlike the short-term parametric test, unit load will be allowed to vary during the long-term tests depending on the load demand for the plant. Potential variations in inlet flue gas mercury concentrations will need to be evaluated with respect to carbon injection rate(s) when planning the long-term tests.

Unit 2 Dual Conditioning ESP System

- Removal of total vapor-phase mercury across the Unit 2 ESP (SCA = 144 ft^2/1000 acfm) during injection of Darco FGD™ activated carbon ranged from 43 to 73 percent at sorbent injection rate ranging from 2.3 lb/MMacf to 12.7 lb/MMacf. The removal curve was relatively flat at about 70 percent for injection rates greater than about 6 lb/MMacf.
- The use of the dual flue gas conditioning system on Unit 2 had no impact on the ability of Darco FGD™ carbon to remove vapor-phase mercury across the ESP.
- With the exception of tests on Day 2 (3/24/04), native removal of total vapor-phase mercury across the Unit 2 ESP ranged from 20 to 36 percent during the various baseline measurement test periods. Native removal on 3/24/04 was as high as 66%, and the highest mercury concentration and LOI were also observed for the ESP ash sample collected during the daily baseline period on 3/24/04.
- Similar to Unit 1, the mercury content of the Unit 2 ESP fly ash increased with increasing LOI during both baseline and Darco FGD™ carbon injection tests. LOI for the Unit 2 ESP ash samples was generally higher compared to Unit 1, ranging from 7 to 22% during the baseline and carbon sorbent injection tests.
- Removal of total vapor-phase mercury for the Unit 1 ESP was higher than that observed for the Unit 2 ESP at the lower Darco FGD™ carbon injection rates of 2 lb/MMacf and 4 lb/MMacf; however, removal curves for both the Unit 1 and Unit 2 ESPs were relatively flat at about 70 percent removal beyond injection rates of 6 lb/MMacf. Native removal of total vapor-phase mercury was similar for both the Unit 1 and Unit 2 ESPs.

5.0 Activities Scheduled for Next Quarter

The next quarterly reporting period covers the period April 1, 2004 through June 30, 2004. The primary activities planned for this period are completion of the parametric tests using the Super HOK activated carbon on Unit 1, continued data evaluation for the Unit 1 and Unit 2 parametric tests, initial preparation of the site test report for all of the parametric tests conducted on Units 1 and 2, selection of the activated carbon sorbent to be used during the long-term tests on Unit 1, and selection of the appropriate sorbent injection rate(s) to be used during the Unit 1 long-term test phase.

6.0 References

None for this document.